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THE UNIVERSITY OF ALBERTA

The Development and Chemistry of Muskiki and Marguerite Lake Peatlands, Central Alberta

by

Helen Jean Kubiw

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF M.Sc.

IN

Peatland Ecology

Department of Botany

EDMONTON, ALBERTA

FALL 1987

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THE UNIVERSITY OF ALBERTA

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled The Development and Chemistry of Muskiki and Marguerite Lake Peatlands, Central Alberta submitted by Helen Jean Kubiw in partial fulfilment of the requirements for the degree of M.Sc. in Peatland Ecology.

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Abstract

The peat and water chemistry, and peat stratigraphy of fens at Muskiki Lake (52° 50'N, 116° 51'W) and Marguerite Lake (54° 38'N, 110° 43'W) in central Alberta were examined in order to determine the general nature of these peatlands and their developmental histories. Muskiki Lake peatland is an extreme rich fen with high cation status, especially calcium and magnesium, and pH greater than 7.0. Marguerite Lake peatland is a transitional rich fen with lower pH (5.9-6.7) and lower calcium concentrations. Nitrogen content of the water, as well as total elemental content of Ca, Mg, Na and K, indicate that differences exist both within and between peatlands.

The stratigraphy at Muskiki Lake peatland suggests that peat accumulation began via lake filling about 9000 years B.P. Expansion of this peatland by paludification, and vegetation changes, including string-and-flark formation, followed in response to subsequent environmental events, including a mid-Holocene thermal event.

Peat inception at Marguerite Lake began about 3400 years B.P. via paludification. This delay, relative to Muskiki Lake peatland, may be due to a later deglaciation and the mid-Holocene warm period. Fire activity and increased wetness, as well as autogenic successional processes, altered species composition and abundance.

The chemical and physical characteristics of the peat provide some clues to the environments in which the peat was

laid down, particularly with respect to moisture conditions.

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List of Abbreviations

Al	aluminum
B.P.	before present
^{14}C	carbon-14 (radiocarbon)
°C	degree Celsius
Ca	calcium
cm	centimetre
Cu	copper
Fe	iron
g	gram
K	potassium
km	kilometre
m	metre
Mg	magnesium
ml	millilitre
mm	millimetre
Mn	manganese
Na	sodium
Ni	nickel
P	phosphorus
Pb	lead
S	sulphur
Ti	titanium
TKN	total kjeldahl nitrogen
yr	year

uS microSiemens

1. General Introduction

Peatlands have been examined from various aspects, including hydrology and water relations (Chapman, 1965; Boelter, 1974; Jeglum, 1975; Glaser *et al.*, 1981); biogeochemical cycles (Crisp, 1966; Damman, 1978; Hemond, 1980), and vegetation gradients (Malmer, 1962; Vitt *et al.*, 1975). Often, the ultimate aim is peatland classification (Zoltai *et al.*, 1975; Pakarinen, 1975; Stanek, 1977), and the wealth of information provided by these numerous studies is invaluable.

As peatland dynamics may often be specific to a particular region, peatland type, or even a single peatland, intensive peatland studies are essential. Few peatlands have been studied completely. Red Lake Peatland in northern Minnesota, however, is an excellent example of a well-studied peatland ecosystem. Studies here have included vegetation and floristics (Heinselman, 1963; Griffin, 1975); biogeochemistry (Glaser *et al.*, 1981); bryology (Janssens, 1983); palaeoecology (Griffin, 1975; Foster *et al.*, 1983); and hydrology (Siegel, 1983). Similar extensive research is being conducted at the Experimental Lakes Area in northwestern Ontario (Schindler *et al.*, 1980; Cook and Schindler, 1983; Vitt and Bayley, 1984).

Comprehensive studies which attempt to determine the relationships between various factors (such as vegetation, peat and water chemistry, and peat stratigraphy) at a single peatland may facilitate interpretive studies of peatland

development.

Interpretive studies may often be based on conjecture if an adequate data base is lacking. Palaeoecological studies of peatland development require sufficient information regarding present-day peatland floras and communities, and ecological relationships in order for interpretations to be valid. This, of course, presupposes the acceptability of the concept of uniformitarianism (i.e., the present is the key to the past) (cf. Simpson, 1970).

As few peatlands have been studied extensively, many peatland developmental studies require the accumulation of preliminary information. The collection of an adequate data base for interpretive studies at a particular peatland may seem overwhelming. The intimidation of a formidable research task, however, should not discourage its undertaking. It would seem preferable to make initial observations regarding, for example, present-day vegetation, chemistry, and peat stratigraphy at a specific peatland, and, coupled with a basic knowledge of peatland dynamics, to conceive preliminary interpretations regarding its developmental history. The acquisition of additional information would allow revision of these initial interpretations, if required.

This thesis consists of two papers based on peatland investigations at Muskiki Lake (52° 50'N, 116°) 51'W) and Marguerite Lake (54° 38'N, 110° 43'W), Alberta. Chapter I deals with the examination of peat water chemistry and the

chemical and physical characteristics of the peat as a function of depth. The investigation of the developmental histories of these two peatlands, based on quantitative macrofossil analyses and radiocarbon dating, is the subject of Chapter II. An attempt to relate peatland development to intrinsic and extrinsic factors of ecological importance will also be made.

These preliminary studies may indicate the similarities and differences in the developmental histories of these peatlands, for although both are fens located adjacent to lakes in central Alberta, each site underwent distinctly different glacial histories. Furthermore, this research may provide additional information regarding the general nature of peatlands in Alberta.

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2. Peat and peat water chemistry at Muskiki Lake and Marguerite Lake peatlands, Alberta, Canada

Nearly 18% of Canada's total land area is estimated to be covered by peatlands (Zoltai and Pollett, 1983). Alberta alone has about 160,000 km² of peatlands (Zoltai and Johnson, 1983), yet it is only in the last 15 to 20 years that a concentrated effort has been made in Canada to understand these inherently complex ecosystems.

Most of the Canadian peatland studies of the 1920's through the 1950's (Lewis and Dowding, 1926; Lewis et el., 1928; Hansen, 1949; Hansen, 1952; Moss, 1953; Sjors, 1959) were intensive descriptive studies of individual sites. Since then, many studies have centered on the classification of peatlands in order to facilitate interpretations of their ecology, development, and floristics.

Numerous factors can be examined in the conception of a peatland classification system, including floristics, topography, drainage patterns, chemistry, string-and-flark patterns, and climate. However, the most fundamental basis for peatland classification systems remains the source of nutrients. Systems dependent on precipitation for water and nutrients are ombrotrophic, while those receiving terrestrial inputs of minerals and water are minerotrophic. This basic difference is used to differentiate between ombrotrophic bogs and minerotrophic fens (Gore, 1983).

Regardless of the source of inputs, differences exist within and between peatlands with respect to the types and

concentrations of elements present, and, more specifically, with respect to the movement of such elements.

The chemical status of a peatland is important, as it can be indicative of its nutritive value for plant growth. For example, the bog-fen classification can be expanded along a poor-rich vegetation gradient which can be related to the chemistry of the peatland, particularly its acid-base status, calcium content, and conductivity (Malmer, 1986). Four classes exist in this vegetation gradient: bog, poor fen, intermediate fen, and rich fen. Bog waters are strongly acidic, have low conductivity and calcium content, and are dominated by H^+ and SO_4^{-2} ions (Gorham and Pearsall, 1956; Clymo, 1963; Gorham, 1978; Glaser, 1983; Malmer, 1986). Rich fens, on the other hand, are characterized by water of high pH, high conductivity, and a high concentration of metal cations such as Ca^{+2} (Vitt *et al.*, 1975; Glaser, 1983; Malmer, 1986).

Numerous studies have emphasized water chemistry as an integral component of a peatland's nature (Sjors, 1952; Gorham, 1956; Gorham and Pearsall, 1956; Clymo, 1963; Heinselman, 1963; Heinselman, 1970; Jeglum, 1971; Vitt *et al.*, 1975; Vitt and Slack, 1975; Hemond, 1980; Slack *et al.*, 1980; Glaser *et al.*, 1981; Siegel, 1983; Karlin and Bliss, 1984; Vitt and Bayley, 1984; Vitt and Slack, 1984; Wieder, 1985). However the poor-rich gradient, as dependent on water chemistry, may only be evident in the surface peat. Typically, bogs, with their acidic waters, are dominated by

species of *Sphagnum*. Giller and Wheeler (1986), on the other hand, found that the pH of water from *Sphagnum* peatlands was not necessarily lower than that of non-*Sphagnum* areas. Furthermore, they found that significant differences in water chemistry were not always reflected in vegetation composition.

More recently, the chemistry of surface inputs as well as peat profiles has been emphasized (Malmer and Sjors, 1955; Gore and Allen, 1956; Kivinen, 1972; Largin *et al*., 1972; Sillanpaa, 1972; Richardson *et al*., 1976; Stanek and Jeglum, 1977; Damman, 1978; Hemond, 1980; Wieder, 1985; Zoltai and Johnson, 1985; Giller and Wheeler, 1986). Numerous factors, both internal and external, and past and present, determine the chemical composition of the peat. The source of inputs, whether geologic, hydrogeologic, atmospheric or anthropogenic, is of considerable importance. Calcium, for example, has many geological sources, including feldspar, calcite, and dolomite, and is perhaps the most abundant dissolved cation in natural fresh waters (Faust and Aly, 1981).

The nature of the peat deposit itself can influence the accumulation, translocation and exchangeability of the elements. Differences in the chemical content of the peat have been related to botanical composition (Gorham, 1957; Largin *et al*., 1972; Giller and Wheeler, 1986). Chapman (1964) found that *Sphagnum-Eriophorum* peat at Coom Rigg Moss, Northumberland, had a much lower exchangeable calcium

and magnesium content than did *Phragmites* peat. The degree of humification can also influence the elemental content of the peat (Ruhling and Tyler, 1970; Hemond, 1980). The environmental conditions *in situ* can also affect the elemental content of peat deposits. Reducing conditions, for example, will increase the solubility of iron and phosphorus (Richardson *et al.*, 1978). Finally, the presence and distribution of the elements will depend on the form and nature of the elements themselves, for some (such as nickel, copper, and iron) bind more readily to humic materials (Nissenbaum and Swaine, 1976).

Owing to the importance of elemental dynamics in peatlands, this study examined the distribution of elements in peat profiles from two peatlands in central Alberta. Furthermore, water chemistry and the physical characteristics of the peat (bulk density, ash content, and moisture content) were also examined in order to clarify these distributional patterns, both within and between peatlands. As the main focus of this research was the examination of the developmental histories of the peatlands at Muskiki and Marguerite Lakes, Alberta, it was hoped that determination of the chemical and physical characteristics of the peat stratigraphies could help explain past developmental processes.

The objectives of this study are to: 1)investigate peat water chemistry, and the chemical and physical properties of the peat as a function of depth; and, 2)relate peatland

chemistry to intrinsic and extrinsic factors influencing peatland dynamics.

2.1 Study sites

Two peatlands in central Alberta were examined (Figure I-1). The first is located in the Rocky Mountain foothills region of Alberta (52°50'N, 116°51'W), about 225 km southwest of Edmonton, Alberta. This fen, adjacent to Muskiki Lake, is situated in a deep valley at an elevation of 1560 m above sea level.

The regional vegetation is dominated by *Picea engelmannii* Parry ex. Engelm. stands, with some *Pinus contorta* Loudon and *Picea glauca* (Moench) Voss. The vegetation is representative of the Subalpine Forest region, East-slope Rockies (SA.1) section (Rowe, 1972).

This study site may lie in the ice-free corridor (Figure I-1) between the Laurentide ice sheet which advanced from the northeast, and the Cordilleran glaciers of the Rocky Mountains to the west. Estimates regarding the opening of the corridor range from about 18,500 years B.P. (Jackson, 1979) to over 100,000 years B.P. (Reeves, 1970). However, evidence indicates that this corridor probably became free of ice about 20,000-40,000 years B.P. (Rutter, 1980).

The peatland itself covers an area of about 33 hectares, on the southeastern side of Muskiki Lake (Plate I-1). It is an elliptical-shaped fen with a long axis of approximately 1440 m along the direction of drainage, with a

maximum width of 360 m. A water track through the peatland is discernible on the airphoto, as is a small creek, dominated by *Menyanthes trifoliata* L., at the farthest end from the lake. Drainage occurs from the lake through the peatland, in the direction of microsites FL3 to FL1 to FL2.

String and flark patterning is discernible in approximately the middle half of the peatland (Plate I-1). Strings, such as microsite FL1 which is located about 804 m from the lake's edge, rise about 40 to 80 cm above the flarks, and are dominated by *Picea mariana* (Mill.) B.S.P., *Betula glandulosa* Michx., and such Cyperaceae, as *Carex lasiocarpa* Ehrh., and *Scirpus caespitosus* L. Bryophytes dominating these strings include *Sphagnum warnstorfii* Russ., *Sphagnum fuscum* (Schimp.) Klinggr., *Aulacomnium palustre* (Hedw.) Schwaegr., *Dicranum undulatum* Brid., and *Tomenthypnum nitens* (Hedw.) Loeske.

Microsite FL2 is a flark located about 912 m from the edge of Muskiki Lake. Broad flarks, such as FL2, are often marl pools which are dominated by brown mosses (family Amblystegiaceae), such as *Scorpidium scorpioides* (Hedw.) Limpr., *Campylium stellatum* (Hedw.) C. Jens., and *Calliergon richardsonii* (Mitt.) Kindb. *ex* Warnst., as well as a scattered cover of such herbaceous species as *Equisetum fluviatile* L., *Scirpus caespitosus* L., and *Menyanthes trifoliata*.

The vegetation closest to the lake, where microsite FL3 is located (168 m from the lake), lacks obvious patterning

of strings and flarks, although there are several raised areas and shallow depressions with pools. Generally, the vegetation reflects the hummock and hollow nature of this area of the peatland. Hummocky areas are dominated by such bryophytes as *Sphagnum fuscum*, *S. warnstorfii*, *Aulacomnium palustre*, and *Tomenthypnum nitens*, and vascular plant species such as *Betula glandulosa*, and *Picea mariana*.

Climatic records from nearby Nordegg (about 60 km southeast of Muskiki Lake) indicate a climate of cold winters, and cool, short summers. Mean annual temperature (1951-1980 average) is 0.7°C. Total annual precipitation is 555.2 mm, with an average annual winter snowfall of 181.2 cm.

The second study site is located adjacent to Marguerite Lake (54°38'N, 110°43'W), about 30 km west of Cold Lake, Alberta, and about 250 km northeast of Edmonton.

The regional geomorphology indicates past glacial activity in the area (Plate I-2). The low-relief hummocky ground moraine which may have originated from basal ice that became inactive during recession of the glaciers, or through ablation, is not uncommon in this area, for it is believed that the broad marginal parts of the Laurentide ice sheet became inactive here (Prest, 1983).

This peatland is located in a shallow basin (elevation 640 m above sea level) between two lakes, and is flanked on both sides by upland areas of forests of *Pinus banksiana* Lamb. and *Picea glauca*, or *Pinus banksiana*, *Populus*

tremuloides Michx. and *Betula papyrifera* Marsh. Rowe (1972) classified this vegetation as representative of the Boreal Forest region, section Mixedwood (B.18a).

The Marguerite Lake peatland, which covers about 295.2 hectares, is much larger than the Muskiki Lake peatland. The size and irregular shape of this peatland appears to be the result of the integration of two peatlands, one adjacent to Marguerite Lake, and the second adjacent to a smaller unnamed lake about 2970 m north-northeast of Marguerite Lake. Drainage of the lake and peatland is probably into Wolf Lake to the northwest. Inputs from the surrounding uplands are probably minimal.

Microsite ML1 is located about 1290 m north of the lake. It is a dry, hummocky site, dominated by regenerating *Larix laricina* (DuRoi) K. Koch. Most trees range from 0.5 to 8.0 m in height, and have a mean age of 23 ± 1.6 years. Some snag and deadfall is present. Other vascular plant species present include *Betula glandulosa*, *Salix pedicellaris* Pursh., *Potentilla palustris*(L.)Scop., and *Ledum groenlandicum* Oeder..

Although the hummocks range from 10 to 40 cm in height, the hollows are quite narrow. Very few pools with standing water were observed in August, 1984, and August, 1985. Typical hummock formers include *Tomenthypnum nitens*, *Aulacomnium palustre*, *Sphagnum nemoreum* Scop. and *Helodium blandowii* (Web. & Mohr) Warnst., with *Drepanocladus vernicosus* (Mitt.) Warnst., *D. revolvens* (Sw.) Warnst., and

Sphagnum warnstorfii found in the hollows and intermediate portions of the hummock-hollow gradient. Although the airphoto (Plate I-2) indicates some patterning close to the lake, along the direction of drainage, strings and flarks were not evident on the ground.

The vegetation of sites ML2 and ML3 is dominated by brown mosses and *Carex* species. Dominant bryophytes include *Calliergon trifarium* (Web. & Mohr) Kindb., *Campylium stellatum*, *Scorpidium scorpioides*, and *Drepanocladus revolvens*. Vascular plants present include some shrubs, such as *Betula glandulosa*, *Salix pedicellaris*, and *Potentilla palustris*; carices, including *Carex lasiocarpa*, *C. diandra* Schrank, and *C. paupercula* Michx. and several herbaceous species as *Menyanthes trifoliata* and *Equisetum fluviatile*.

The climate for the Marguerite Lake area, as recorded at the Cold Lake Airport, 30 km east, is very similar to that of the foothills area, in that the summers are cool and short, and the winters are cold. Mean annual temperature is somewhat higher at 1.2°C, with less total annual precipitation (459.9 mm) and winter snowfall (135.4 cm), and higher average moisture deficit (15 cm).

Differences in climate, vegetation, bedrock and surficial deposits at Muskiki and Marguerite Lakes are summarized in Table I-1.

2.2 Methods

Present-day vegetation was described by releve method, and cover abundance was estimated on a 7-part scale (+=less than 1%; 1= 1-5%; 2=6-25%; 3=26-50%; 4=51-75%; 5=76-95%; 6=96-100%).

Peat cores were recovered from three microsites within each peatland, using a modified McCauley peat corer, with an inside diameter of five cm and length of 50 cm. Peat horizons and the underlying mineral soil were identified and designated according to the Canadian soil classification system (Canada Soil Survey Committee, 1978). Furthermore, pH and von Post degree of humification of the wet peat horizons were determined.

For each horizon identified in the core, a 10 cm sample was recovered for bulk density analysis. A second sample 5-15 cm in length was taken for chemical analysis. Peat samples were oven-dried at 55°C, and weighed to determine moisture content (%), and bulk density. Bulk density was calculated as the oven dry weight per unit of undisturbed core volume. These samples were heated at 550°C in a muffle furnace, weighed, and the ash content determined.

For chemical analyses, the ash was dissolved in 1.5 HCl and concentrated HNO_3. The peat extract was analyzed for total elemental content (mg/g dry weight) of Ca, Mg, Na, K, Al, Ti, Pb, Cu, Fe, Mn, Ni, S, and P by inductively coupled argon plasma spectrophotometry (ICPS) at the Canadian Forestry Service's Northern Forestry Centre, Edmonton.

Results are presented on a total and ash-free basis.

Water samples were taken from pools or shallow pits, between August 10 and 15, 1985, and analyzed immediately for pH using an Aqua-Digitester. Conductivity was measured on water samples at 20°C within 48 hours, using a Radiometer Copenhagen Conductivity Meter (CDM 2E).

Two more sets of water samples were taken and kept cold and later analyzed for: 1)total Kjeldahl nitrogen, using a Bausch and Lomb Spectronic 710 spectrophotometer; 2)nitrite, nitrate, and ammonia, colorimetrically determined by a Technicon autoanalyzer; and, 3)ionic content (mg/l) of Ca, Mg, Na, K, Al, Ti, Pb, Cu, Fe, Mn, Zn, Ni, S, and P, by inductively coupled argon plasma spectrophotometry.

2.3 Results

2.3.1 Muskiki Lake peatland

Species lists and cover abundance data for taxa encountered at all microsites are provided in Table I-2.

2.3.1.1 Water chemistry

Within the Muskiki Lake peatland, pH ranges from 6.83 at microsite FL3 (168 m from the lake) to 7.74 for the lake water (Table I-3), with intermediate pH values on the string (microsite FL1) and flark (microsite FL2). Conductivity ranges from 121.5±7.8 µS in the lake water, to 204.0±1.9 µS in the water samples from the marl pools

of the flarks.

Results from total elemental analyses are presented in Appendix 5-1. Calcium concentrations range from 32.0 to 64.3 mg/l, with highest values in the flark water, and lowest values in the lake water. Minimal differences in magnesium content are evident at the three peatland microsites (11.3, 12.3, and 14.0 mg/l), although somewhat lower values are found in the lake water (8.7 mg/l). Sodium concentrations in the Muskiki Lake peatland water samples are fairly low, generally less than 2.7 mg/l, except for lake water, which has as average concentration of 3.8±0.4 mg/l. Similarly, potassium concentrations are very low, ranging from 0.30 mg/l in the flark water, to 1.1 mg/l at microsite FL3. Except for Ca, Mg, Na, and K, most elements are present in minimal concentrations, often less than the detection limits of the ICPS.

Although nitrogen, in the forms of nitrate, nitrate and ammonia, is virtually absent or in low concentrations in all Muskiki Lake peatland water samples (Table I-3), it is evident that the bulk of N in these peatland waters is in the form of organic N. Total Kjeldahl nitrogen (organic N + ammonia) ranges from 400.5 µg/l to 2724.8 µg/l.

2.3.1.2 Peat analyses

Three peat cores were recovered from Muskiki Lake peatland, at microsites FL1, FL2, and FL3 (Plate I-1).

Microsite FL1, located on a string about 840 m from the lake, records a peat depth of 371 cm, overlying a blue-gray lacustrine clay. The upper 286 cm consists of fibric horizons (Of) (Appendix 5-2) with von Post values of 2 to 4, indicative of poor to low humification. Mesic horizons (Om) generally dominate the lowermost peat, and moderate humification is indicated by von Post values of 5 and 6. Anomalies include two volcanic ashes at 124-130 cm and 304-311 cm, and a fibric inclusion of mosses at 340-362 cm.

Located in a broad flark about 912 m from Muskiki Lake, microsite FL2 records a peat depth of 384 cm, overlying a gray clay with stone inclusions. The upper 172 cm of peat is fibric, with von Post values of 2 to 4 (Appendix 5-2). The remainder of the core (172-384 cm) is generally mesic, with von Post values of 6 and 7. Two volcanic ashes were observed at depths of 137-140 cm and 262-277 cm.

Microsite FL3, located about 168 m from Muskiki Lake, records a peat depth of 527 cm, above layers of gyttja, sand and clay. Horizon designations (Appendix 5-2) indicate that, with only a few exceptions,: 1) the uppermost peat (0-134 cm) is fibric; 2) mesic (134-241 cm); 3) fibric (241-414 cm); and 4) humic (414-527 cm). Volcanic ashes occur at depths of 109-134 cm and 222-232 cm, and a clay inclusion appears at 271-289 cm depth. Fibric horizons have von Post values of 2 to 4, whereas

mesic horizons range from 5 to 6, and the most humified layers have von Post values of 7 and 8.

Peat pH at these three microsites (Appendix 5-2) typically increases slightly with depth, such that the upper horizons record values of pH 6.0 and the deeper horizons have pH values of 6.0 to 6.5.

Physical characteristics

Figure I-2 indicates the changes in ash content and dry bulk density with peat depth at microsites FL1, FL2, and FL3. The ash content of the peat generally ranges from 7-18%, except where volcanic tephras and inorganic horizons are present, with ash content of 48-89%. Dry bulk density (g dry matter/cm^3), (Figure I-2), which is well correlated with ash content at all three microsites (Appendix 5-3), typically ranges from 0.09 to 0.66 g/cm^3 except where a volcanic ash or mineral soil is present.

Moisture content (Appendix 5-2) of the peat is quite high, ranging from 77-92%, although lower values were observed in the inorganic layers of tephras and mineral soil. Moisture is significantly negatively correlated with both ash content and bulk density (Appendix 5-3).

Chemical characteristics

High calcium concentrations (Figure I-3) are evident throughout the peat cores from microsites FL1,

and FL3. The calcium content of most horizons ranges from 19.9 to 42.6 mg/g (6.7-36.3 mg/g, ash-free), indicative of a rich fen. Consistent trends in calcium concentrations with depth are not evident. Magnesium concentrations, which range from 1.3 to 6.2 mg/g (1.1-3.0 mg/g, ash-free), typically show no or only slight decreases with depth (Figure I-4).

Concentrations of sodium and potassium (Figures I-5 and I-6) are very low in the peat at Muskiki Lake peatland (less than 0.5 mg/g) and generally decrease with depth. These trends may be masked by unusually high concentrations of these two elements in the inorganic inclusions.

Except for Ca, Mg, Na, and K, most elements are present in very low concentrations (except in the mineral horizons) (Appendix 5-4). Although the concentrations of Cu and Al change very little with peat depth, some elements (S and Fe, for example) may show increasing concentrations with depth. Concentrations of magnesium, lead and nickel, however, either increase, decrease, or remain stable with peat depth, depending on the microsite. Increases in titanium concentration strongly indicate the presence of the two tephras (Figure I-7).

2.3.2 Marguerite Lake peatland

Present-day vegetation and cover abundance at Marguerite Lake peatland is listed in Table I-2.

2.3.2.1 Water chemistry

pH of the water samples from Marguerite Lake and its peatland are generally lower than those from Muskiki Lake peatland (Table I-3). pH ranges from 5.9±0.05 (microsite ML1) to 6.7±0.05 (lake). Similar to water samples from Muskiki Lake peatland, highest pH values are found in lake water, and lowest at the driest microsite. pH of the water samples decreases with distance from the lake.

The range of water conductivity values is much greater at this peatland relative to Muskiki (Table I-3). The lowest conductivity (59.9 µS) was detected at microsite ML1, and the highest (316.6 µS) in the lake water. A trend of decreasing conductivity with distance from the lake is evident.

At Marguerite Lake peatland, calcium concentrations in the water is fairly constant between microsites, ranging from 20.8 to 33.3 mg/l (Appendix 5-1). Lowest concentrations are found in the driest microsite and the highest in the lake water.

Magnesium content, on the other hand, is wide ranging (5.6-54.7 mg/l) between microsites.

Sodium concentrations in the water from Marguerite Lake peatland, ranging from 2.4 mg/l at the driest

microsite to 13.4 mg/l in the lake water, are typically greater than those from Muskiki water samples. A decrease in Na concentrations with distance from the lake is evident.

Potassium is also found in higher concentrations in Marguerite water samples. Concentrations of K are fairly low (1.0-7.6 mg/l).

Overall, nitrogen content in Marguerite water samples is much greater than in Muskiki Lake peatland water samples (Table I-3). Nitrite and nitrate range from 6.8 to 13.4 µg/l. Ammonia concentrations are generally higher (12.2-109.7 µg/l). Total Kjeldahl nitrogen content is fairly high, with highest values in microsite ML3's water (3438 µg/l) and in the lake water (3351 µg/l). The majority of TKN is organic nitrogen (Table I-3).

2.3.2.2 Peat analyses

Three peat cores were recovered from Marguerite Lake peatland, at microsites ML1, ML2, and ML3 (Plate I-2).

A 136-cm peat core was recovered from the treed microsite, ML1, which is located about 1290 m from the lake. Most of the peat (0-94 cm) is fibric, as reflected by von Post values which range from 0 to 4 (Appendix 5). Mesic peat (94-136 cm) intercedes between these fibric horizons and the underlying horizons of sand and clay.

Microsite M12, located about 690 m north of Marguerite Lake, produced a peat core of 129 cm in length. The upper six horizons of the eight designated peat layers are fibric (0-119 cm), with von Post values of 3 and 4. The two remaining peat horizons (119-124 cm) are humic, with von Post degree of humification values of 7. Clay underlies the peat.

Microsite ML3, located approximately 330 m from the lake, has a peat depth of 187 cm. The majority of this peat core (0-176 cm) is fibric (von Post values of 2 to 4), with only one mesic horizon present (176-187 cm), with a von Post value of 5. The peat at microsite ML3 lays over several horizons of sand.

Peat pH (Appendix 5-5) is typically higher in the lower horizons (pH 6.5-7.0) than in the surface and upper peat horizons (pH 5-6.5) at all microsites.

Physical characteristics

The inorganic content of the peat, as indicated by the ash content (Figure I-8), shows an increase with depth. The ash content of the upper peat horizons is very low (6.2-8.9%), whereas the most humified peat horizons and mineral layers record much higher ash contents (27-63.8%, and 89-98.2%, respectively).

Dry bulk density (Figure I-8) generally increases with depth, ranging from less than 0.2 g/cm^3 in the upper fibric peat horizons, to 0.2-0.8 g/cm^3 in the

mesic horizons, and 1.2-1.4 g/cm³ in the mineral soil. A positive correlation exists between bulk density and ash content (Appendix 5-6).

Moisture content (Appendix 5-5) decreases with depth, such that the surface and uppermost peats have 82.8-91.8% moisture; the humified peat has 33.3-83.5% moisture; and the underlying mineral soil contains 17.7-53% moisture. A strong negative correlation between moisture content and bulk density is evident at all three microsites (Appendix 5-6).

Chemical characteristics

Calcium and magnesium are the two dominant cations in the peat (Figures I-9 and I-10) at Marguerite Lake peatland. The concentrations of these two elements (Figures I-98 and I-10) may increase slightly with depth, or remain relatively unchanged with depth. Typical calcium and magnesium concentrations range from 1.5 to 24.0 mg/g, and 0.6 to 8.1 mg/g, respectively. The underlying sand horizons of microsites ML1 and ML3 contains little Ca and Mg, although microsite ML2's underlying clay is rich in these two elements.

Sodium and potassium concentrations (Figures I-11 and I-12) at microsites ML2 and ML3 range from 0.10 to 0.50 mg/g and 0.05 to 1.1 mg/g, respectively, much greater than at microsite ML1. At microsite ML1, Na and K concentrations are typically less than 0.03 mg/g.

Although Na concentrations change very little with depth (except in the underlying mineral and adjacent horizons), the highest K content occurs in the surface peat and decreases with increasing depth. Moreover, Na and K concentrations are higher in the sand horizons than in the peat at microsites ML1 and ML3, and lower in the clay at microsite ML2.

Many of the other nine elements examined are found in very low supply (Appendix 5-7). Consistent trends in elemental concentration with depth are not evident. Iron, manganese and sulphur, for example, decrease in content with increasing depth at microsite ML1, but increase with peat depth at microsite ML3.

2.4 Discussion

Peats can be evaluated and classified on a variety of parameters, including the physical and chemical characteristics examined in this paper. Due to the variation observed within and between peatlands, each parameter or set of parameters is examined separately, such that a general discussion of peat and water chemistry is possible.

2.4.1 Water chemistry

Based on the chemistry of peat water from Muskiki and Marguerite Lakes' peatlands, these two peatlands can be typed as rich fen. High pH (6.8-7.7), high conductivity (121.4-203.9 µS), and high cation status (particularly Ca

and Mg) support the designation of Muskiki Lake peatland as an extreme rich fen. At Marguerite Lake, lower pH (5.9-6.7) and lower Ca concentrations, with high conductivity, indicate a transitional-rich fen (Sjors, 1952).

These designations along a poor-rich gradient may be acceptable based on surface water chemistry. Higher pH values at greater depths, however, are not unusual, perhaps due to a "pickling" effect (Zoltai and Johnson, 1985; Giller and Wheeler, 1986). Nevertheless, these vertical fluctuations are typically minimal relative to the classification gradients.

Nitrogen concentrations in the peat water from Muskiki and Marguerite Lakes' peatlands suggest a major difference between sites. Dissolved and extractable N is very low at both sites, probably due to low mineralization rates and high denitrification (Giller and Wheeler, 1986). Total nitrogen, mostly organic, is very high, particularly at Marguerite Lake.

As the actual lake water also suggests differences between the two peatlands, it is unlikely that differential plant uptake is responsible. Both peatlands are minerotrophic and, thus, inputs of nutrients are both from above via precipitation and from below via groundwater, underlying soil, and bedrock. As it is unlikely that major differences in atmospheric inputs occur between sites, differences in regional bedrock and soils are undoubtedly responsible.

2.4.2 Physical characteristics

The physical characteristics of a peat can be useful both directly as evidence of a peat's attributes and indirectly in interpretive studies.

Dry bulk density is significantly correlated with ash content (Nichols and Boelter, 1984), thereby allowing identification of anomalous inclusions of inorganic soils and tephras by unusually high bulk density values.

The physical characterisitcs of a peat, namely bulk density, percent ash, and percent moisture, give important direct evidence of the degree of peat humification, a property considered important for peat classification systems (Kivinen, 1981). Bulk density which typically increases with increasing depth is strongly correlated with the degree of peat decomposition (Nichols and Boelter, 1984).

The stratigraphic variability of elemental content throughout a peat core may be reflective of differences in bulk density, and perhaps the degree of humification. Sillanpaa (1972) suggested that differences in elemental concentrations seen in peat stratigraphies may be significantly reduced if concentrations were made on a dry weight basis rather than on a volume basis which disregards differences due to compaction, humification, and moisture.

The value of these physical characteristics in palaeoecological interpretations is undeniable. Aaby and Tauber (1975) suggest that the degree of peat humification

may be reflective of the climatic conditions at the time of peat accumulation. A fibric, poorly decomposed peat, suggesting rapid peat accumulation, may be indicative of wet conditions, whereas a very humic peat with a high bulk density may suggest poor peat growth and, thus, drier conditions. Coupled with radiocarbon dates, bulk density allows determination of net organic production ($g/cm^2/yr$) which quantifies differences in peat accumulation.

2.4.3 Tephras

Two tephras (specifically volcanic ashes) were recognized in the peat cores from Muskiki Lake peatland. In the field, these tephras appeared as dry, yellow deposits, forming distinct horizons.

As most researchers are acquainted with regional tephras, field identification of a tephra is possible. However, detailed physical and chemical studies of the deposits are often essential for accurate identification of tephras (Steen and Fryxell, 1965; Dudas *et al.*, 1973; Smith and Westgate, 1969). Bulk chemical analyses via inductively coupled argon plasma spectrophotometry allow differentiation of the tephras, as tephras generally differ in their elemental content (Smith and Westgate, 1969).

Based on Smith and Westgate's (1969) electron probe study, the two ashes in the Muskiki Lake peat were determined to be Mazama and St. Helens Y. Mazama ash originated from Mount Mazama at Crater Lake, Oregon, about

6600 years B.P. (Wilcox, 1965; Fryxell, 1965). It was identified in these peat cores based on the lower Ca content, high Ti, and relatively high K. St. Helens Y volcanic ash originated from an eruption of Mount St. Helens, Washington, about 3500 years B.P. (Westgate *et al.*, 1969). This tephra is suggested by the higher Ca content and very low K (Smith and Westgate, 1969).

2.4.4 Calcium and magnesium

Calcium and magnesium are the major elemental constituents of the peat at both peatlands studied, which is reflective of their abundance in natural waters and their wide distribution in rocks and soils. The distribution of these elements in these peat profiles, however, cannot be typified, as Ca and Mg have been observed to increase with depth or show no change with depth. Previous studies (Chapman, 1964; Kivinen, 1972; Damman, 1978; Hemond, 1980; Percy and Borland, 1985) have also shown variation in the distribution patterns of Ca and Mg in peat.

The amount of adsorbed Ca and Mg is very great(Damman, 1978), as these cations form stable complexes with organic acids via chelation (Bruggenwert and Kamphorst, 1979). Only minimal losses occur due to translocation, except below the anaerobic zone.

Increases in Ca and Mg at greater depths could be related to losses below the anaerobic zone *i.e.* the water table. Damman (1978) suggested that the depth to the water

table, as well as changes in redox potential, will determine the degree to which Ca and Mg are either adsorbed or exchanged. However, a change in the peat's ion exchange chemistry with increasing depth, such as with the onset of *Sphagnum* peat at some sites, may affect the vertical distribution patterns of calcium and magnesium.

As both Marguerite and Muskiki Lake peatlands are minerotrophic, the increases in Ca and Mg concentrations may depend on the bedrock and underlying mineral (Kivinen, 1972). Furthermore, as Ca and Mg concentrations vary significantly between the two peatlands, it suggests that these differences are more related to the bedrock and mineral soils of the region rather than on peat type.

2.4.5 Sodium and potassium

Sodium is present in all cores, although in lower concentration than Ca and Mg. The principal determinant of the ultimate concentration of Na in water is the geological source of the sodium (Faust and Aly, 1981). The calcareous nature of Muskiki Lake and its area explains the lower Na concentrations at this site compared to Marguerite Lake.

The paucity of Na in these deposits may be due to sodium's tendency to remain in solution (Faust and Aly, 1981) and to be rapidly exchanged and removed from peatlands. At Marguerite Lake, Na concentrations change very little with peat depth, whereas at Muskiki Lake, sodium concentrates in the surface vegetation and upper peat

layers, and decreases with depth. These distributional patterns have been reported previously (Kivinen, 1972; Aaby and Jacobsen, 1978). The increase in sodium in the clay horizons, such as at microsite FL3, can be attributed to the adsorption of Na ions from solution onto clay surfaces where ion exchange reactions occur (Faust and Aly, 1981).

Potassium has a similar chemistry to sodium, since it is generally in short supply in all peats (Kivinen, 1972) and can concentrate in the surface vegetation and surface peat (Kivinen, 1972; Aaby and Jacobsen, 1978; Damman, 1978) as it does at Muskiki Lake peatland. K also tends to remain in solution as it seldom enters into precipitous reactions that could control its solubility (Faust and Aly, 1981). Potasssium, however, will undergo ion exchange reactions, which explains potassium's high mobility (Summerfield, 1974), and decreases in potassium concentrations with increasing peat depth at Muskiki Lake.

There may also be some relationship between concentration differences and vegetation type (Kivinen, 1972). At Marguerite Lake, Na and K are found in higher concentrations at the drier, *Larix-Sphagnum* site that at the sedge dominated sites. Differential uptake may be responsible.

2.4.6 Lead, copper, and nickel

Heavy metal pollution has been a growing environmental concern over the last 15 to 20 years. Due to the sensitivity

of many bryophytes to pollution, numerous studies have examined the metal content of mosses and their responses to such inputs (Ruhling and Tyler, 1970; Pakarinen and Tolonen, 1976; Glooschenko and Capobianco, 1978; Aulio, 1985; Lembrechts and Vanderbroght, 1985). Studies on peat deposits may also be informative as a reflection of the history of metal pollution (Aaby and Jacobsen, 1978).

The distribution of lead in peat is particularly useful, as peat has a high affintiy for lead. In nature, Pb exists mainly as a sulfide which has a very low solubility in water and forms stable complexes with organic matter (Faust and Aly, 1981).

The even distribution of lead through the peat profiles emphasizes the peat's capacity for binding Pb, as well as suggesting limited inputs of lead into these systems. Common sources of lead include deposits of lead ore and man-made sources, such as mining fallout, automobiles, and industrial sources. With the remoteness of these two peatlands, little Pb is expected in the cores. Higher concentrations are found at Muskiki Lake, probably due to the site's proximity to a forestry trunk road and and to former strip-mining operations at nearby Mountain Park, Alberta.

The mobility of copper and nickel, like lead, and other heavy metals, may be influenced by complexing with organic compounds. Nissenbaum and Swaine (1976) found that a great portion of copper and nickel may bind to humic materials, under reducing conditions, such that they are virtually

immobile. Although a portion of copper may be fairly mobile and re-exchanged by repeated leaching as binding sites become occupied by trivalent cations such as Fe and Al, as well as Cu, (Stevenson and Fitch, 1981), the relatively even distribution of Cu in the peat cores indicates retention, probably due to chelation (Ruhling and Tyler, 1970).

Nickel may show great mobility, for it is chiefly absorbed by passive ion exchange (Ruhling and Tyler, 1970). At Muskiki Lake peatland, increasing Ni concentrations with depth, at several sites, could be related to the high cation exchange capacity of *Sphagnum* peats.

pH may also have a role in decreasing the mobility of Cu and Ni at Marguerite and Muskiki Lakes' peatlands. Most heavy metals become mobile at higher pH levels (Hutchinson, 1980).

The degree of peat decomposition may also affect the mobility of Cu and Ni. Higher accumulations of these elements in the more strongly humified horizons of the peat cores may suggest decreased mobiliity with increasing humification. However, whether these higher concentrations are related to the degree of peat humification, the reducing conditions of the deposit, or simply the result of compaction is unknown.

In most peat cores from Muskiki and Marguerite Lakes, copper and nickel had higher concentrations in the underlying mineral soil than in the peat, probably due to exchange adsorption, precipitation, and the physical

entrapment of the metals in the mineral lattice (Tyler, 1981).

2.4.7 Aluminum, iron, and manganese

Aluminum, iron and manganese are all common rock constituents, although Al is much less soluble than Fe and Mn which are easily weathered chemically from rocks through oxidation-reduction reactions (Faust and Aly, 1981). These three cations are found in trace amounts in the peat and peat water at Muskiki and Marguerite Lakes.

Al generally shows no change in concentration with depth in these peat profile, probably due to the formation of stable complexes with organic acids. Concentrations in the underlying mineral are typically higher, a finding corroborated by Sillanpaa (1972). Under poorly drained conditions in mineral soils, Al tends to remain immobile (Damman, 1978).

The distribution of Fe in these peat deposits indicates an increase in concentration with depth. The immobility of iron, and its accumulation with the breakdown of peat could explain its distribution. However, below the water table, Fe should become ferrous, which is mobile. The binding of Fe to humic materials (Nissenbaum and Swaine, 1976) may be responsible for these increases at lower depths.

Manganese's unusual distribution of decreasing, then increasing concentration with depth can be related to the role of manganese in plant metabolism, as well as to redox

processes and their influence on elemental mobility. High concentrations of Mn at the surface may be due to plant uptake. Below the water table, Mn is reduced from a tetravalent state to a divalent, mobile cation which is removed from the zone of water level fluctuation and the anaerobic zone (Damman, 1978) and accumulates in the mineral soil.

2.4.8 Phosphorus and sulphur

Phosphorus is found in limited quantities in the peat and peat water, probably due to the high insolubility of P-containing minerals. Most of the total phosphorus is in organic form (Jasmin *et al.*, 1981), particularly in aerated peat.

Phosphorus concentrations are generally highest in the surface peat, and decrease with increasing depth. As P is most available and easily leached from soils of pH 6-7 (Wetzel, 1983), and since P is an essential element for biological processes, plant uptake, which is probably very rapid (Giller and Wheeler, 1986), may be responsible for accumulations at the surface.

Phosphorus concentrations are apparently related to Fe and Al concentrations in the peat, particularly in the anaerobic peat. Although most P is organic, some phosphorus may bond to Fe and Al. Below the zone of water table fluctuations, Fe and Al will become mobile, as will P consequently. These elements will be present in very low

concentrations (Damman, 1978), as was observed at Muskiki and Marguerite Lakes.

Sulphur compounds which may have their source in rocks or atmospheric inputs are not usually limiting in soils and natural waters. Sulphur concentrations generally increase with peat depth, reaching a maximum just above the water table. High sulphur concentrations at this transition from aerobic to anaerobic conditions has been found previously (Pakarinen *et al.*, 1980). Sulphur at this layer may be in sulphide or free sulphur forms, although sulphate is probably more prevalent in the aerobic zone, due to biologically-mediated oxidation of reduced S forms (Faust and Aly, 1981).

2.5 Conclusions

Evaluating the physical and chemical characteristics of a peatland is especially important in attaining a comprehensive understanding of peatland ecology, as well as providing an invaluable foundation for peatland classification.

The choice of parameters used in evaluating a peatland is especially critical. Great emphasis has been placed on the poor-rich vegetation gradient which is related to the acid-base status and cation content of peatland waters (Malmer, 1986). Water pH levels and nitrogen status at Marguerite and Muskiki Lakes peatlands indicate that Muskiki is an extreme rich fen whereas Marguerite is a transitional

rich fen. Differences between these two peatlands are corroborated by vegetation, peat stratigraphy, and total elemental analyses.

The chemistry of peatlands has been emphasized, although many studies have focused on the concentration of different elements in surface peats (Malmer and Sjors, 1955; Damman, 1986), and in living plants (Malmer and Sjors, 1955; Ruhling and Tyler, 1970; Glooschenko and Capobianco, 1978). More recently, the examination of elemental changes with depth in the peat profiles, and the factors responsible for their distribution have been examined (Largin *et al.*, 1972; Sillanpaa, 1972; Damman, 1978; Hemond, 1980).

A problem with these chemo-stratigraphic studies lies in their frequent emphasis of a single factor determining the changes evident. Many factors can affect the distribution of an element in a peat deposit, including water table fluctuations (Damman, 1978); the underlying and regional lithology (Kivinen, 1972); uptake by vegetation (Giller and Wheeler, 1986); pH (Hutchinson, 1980); the degree of peat humification (Ruhling and Tyler, 1970; Hemond, 1980); peat composition (Kivinen, 1972; Chapman, 1964); and the adsorption, mobility, and exchange characteristics of the elements (Ruhling and Tyler, 1970; Damman, 1978; Hemond, 1980).

Because so many factors, both internal and external, affect the chemistry of the peat, it would be impossible to claim that the nature of the peat-forming community is

exclusively responsible for determining the elemental content. The corollary of this statement, however, may be more acceptable. The assemblage of a peat horizon is composed of plant species, both bryophytic and vascular, which have specific autecologies. Each species is adapted to or prefers certain environmental conditions, including peatland chemistry. The species composition of each horizon will indirectly reflect the chemistry of the peatland throughout its development. Thus, it should be possible to use peat constituents as indicators of various peatland chemical characteristics. Gorham and Janssens (unpubl.) have attempted to use subfossil bryophytes as indicators of paleo-pH.

In addition to peat chemistry, the physical characteristics of the peat may aid interpretations of peatland development. Bulk density may be indicative of the degree of humification of the peat which may be affected by local moisture conditions. A fibric peat of low bulk density may suggest rapid peat growth and retarded decomposition due to increased wetness (Aaby and Tauber, 1975). Furthermore, bulk density, ash content, and moisture content may reflect indirectly the botanical composition and degree of decomposition of the peat, which are two essential parameters in peat classification (Kivinen, 1972). These physical characterisitics may also help explain the chemical character of peat profiles, as well as providing information regarding anomalous inclusions such as tephras.

In conclusion, the variation exhibited in peat and peat water from Muskiki Lake and Marguerite Lake suggests their value as a basis for peatland classification. High conductivity, higher pH, and lower nitrogen content supports the designation of Muskiki Lake peatland as a rich fen, compared to Marguerite Lake peatland, a transitional rich fen.

Furthermore, examination of various physical characteristics of the peat, including bulk density and ash content, may provide some insight into the general nature of peatlands, and more specifically, into the developmental sequences of these peatlands.

Table I-1. Regional climate, vegetation and geology of Muskiki Lake and Marguerite Lake areas, Alberta.

	Muskiki Lake	Marguerite Lake
Mean annual temperature[1]	0.7°c	1.2°C
Total annual precipitation[1]	555.2 mm	459.9 mm
Average annual snowfall[1]	181.2 cm	135.4 mm
Average potential evapotranspiration[2]	45-50 cm	45-50 cm
Average moisture deficit[2]	5 cm	15 cm
Vegetation[3]	Subalpine Forest region, Eastslope Rockies (SA.1)	Boreal Forest region, Mixedwood (B.18a)
Bedrock	Brazeau Formation[4] (mainly sandstone and shale)	Lea Park Formation[5] (shale)
Surficial Deposits	slightly leached[6] till, with clastic rocks	Silt, Clay and till[5] with sand and gravel

[1] Alberta Environment (1982)
[2] Longley (1972)
[3] Rowe (1972)
[4] MacKay (1943)
[5] Gold et al. (1983)
[6] Alberta Research Council (1980)

Table I-2. Species lists and cover of present-day vegetation at microsites at Muskiki Lake (FL1, FL2, FL3) and Marguerite Lake (ML1, ML2, ML3) peatlands (cover: + = <1%, 1 = 1-5%, 2 = 6-25%, 3 = 26-50%, 4 = 51-75%, 5 = 76-95%, 6 = 96-100%).

Tree & Woody Shrubs	FL1	FL2	FL3	ML1	ML2	ML3
Andromeda polifolia L.	+			1	+	+
Betula glandulosa Michx.	2		2	3	2	1
Chamaedaphne calyculata (L.) Moench.	2					
Empetrum nigrum L.			+			
Larix laricina (DuRoi) K. Koch				2	+	
Ledum groenlandicum Oeder	1		2	+		
Oxycoccus microcarpus Turcz.	+		+	+		
Picea mariana (Mill.) B.S.P.	2		1			
Salix myrtillifolia Anderss.			1			
Salix pedicellaris Pursh	2			+	+	
Vaccinium vitis-idaea L.	+		+			
Herbs						
Aster junciformis Rydb.					+	+
Calamagrostis canadensis (Michx.) Beauv.					1	
Carex diandra Schrank					1	
C. gynocrates Wormsk.	+		+			
C. lasiocarpa Ehrh.	2	2	2	1	2	3
C. paupercula Michx.	+	+			+	+
Castilleja lutescens (Greenm.) Rydb.			+			
Cicuta bulbifera L.						+
Epilobium angustifolium L.						+
Equisetum fluviatile L.		1		+	+	1
Galium labradoricum Wieg.					+	1
Menyanthes trifoliata L.		1			+	1
Pedicularis groenlandica Retz.			+			
P. labradorica Wirsing	+		+			
Polygonum viviparum L.	+	+	+			
Potentilla palustris (L.) Scop.				+		+
Scirpus caespitosus L.	1	2	2			
Smilacina trifolia (L.) Desf.	+			+		
Stellaria longifolia Muhl.						+
Tofieldia glutinosa (Michx.) Pers.	+					
T. pusilla (Michx.) Pers.	+					
Triglochin maritima L.		+			+	1
Utricularia intermedia Hayne		1			+	+
Bryophytes						
Aulacomnium palustre (Hedw.) Schwaegr.	+		1	3		
Bryum pseudotriquetrum (Hedw.) Gaertn.			+	+		+
Calliergon richardsonii (Mitt.) Kindb. ex. Warnst.		1				

C. trifarium (Web. & Mohr) Kindb.		+				
Campylium polygamum (B.S.G.) C. Jens.				+		
C. stellatum (Hedw.) C. Jens.			+			
Dicranum undulatum Brid.	+					
Drepanocladus aduncus (Hedw.) Warnst.				+		
D. revolvens (Sw.) Warnst.			+	1	+	1
D. vernicosus (Mitt.) Warnst.				1		
Helodium blandowii (Web. & Mohr) Warnst.				1		
Meesia triquetra (Richt.) Angstr.						+
Plagiomnium ciliare (C. Müll.) Kop.				+		
Polytrichum strictum Brid.			+	+		
Scorpidium scorpioides (Hedw.) Limpr.		4			3	4
S. turgescens (T. Jens.) Loeske					+	+
Sphagnum fuscum (Schimp.) Klinggr.	3		3	+		
S. magellanicum Brid.			+			
S. nemoreum Scop.			1	1		
S. warnstorfii Russ.	1	1	2	1		
Tomenthypnum nitens (Hedw.) Loeske	1		1	2		

Table 1-3. Chemistry of lake water (FLA, MLA) and peat water (FL1-3, ML1-3) at Muskiki Lake and Marguerite Lake peatlands, respectively.

	pH	Conductivity (uS)	Nitrate & nitrite (ug/l)	Ammonia (ug/l)	Total Kjeldahl (ug/l)	Organic nitrogen
FL1	7.02	163.8	0.0	28.8	1767.3	1738.6
FL2	7.31	204.0	0.0	0.2	656.1	655.9
FL3	6.83	180.8	0.3	265.8	2724.8	2459.0
FLA	7.74	121.5	0.0	0.5	400.5	400.0
ML1	5.91	59.9	13.4	12.2	2911.5	2899.3
ML2	6.17	150.0	6.8	50.6	2773.2	2722.6
ML3	6.53	225.4	7.6	199.7	3439.2	3329.5
ML4	6.74	316.6	11.9	28.7	3351.3	3322.6

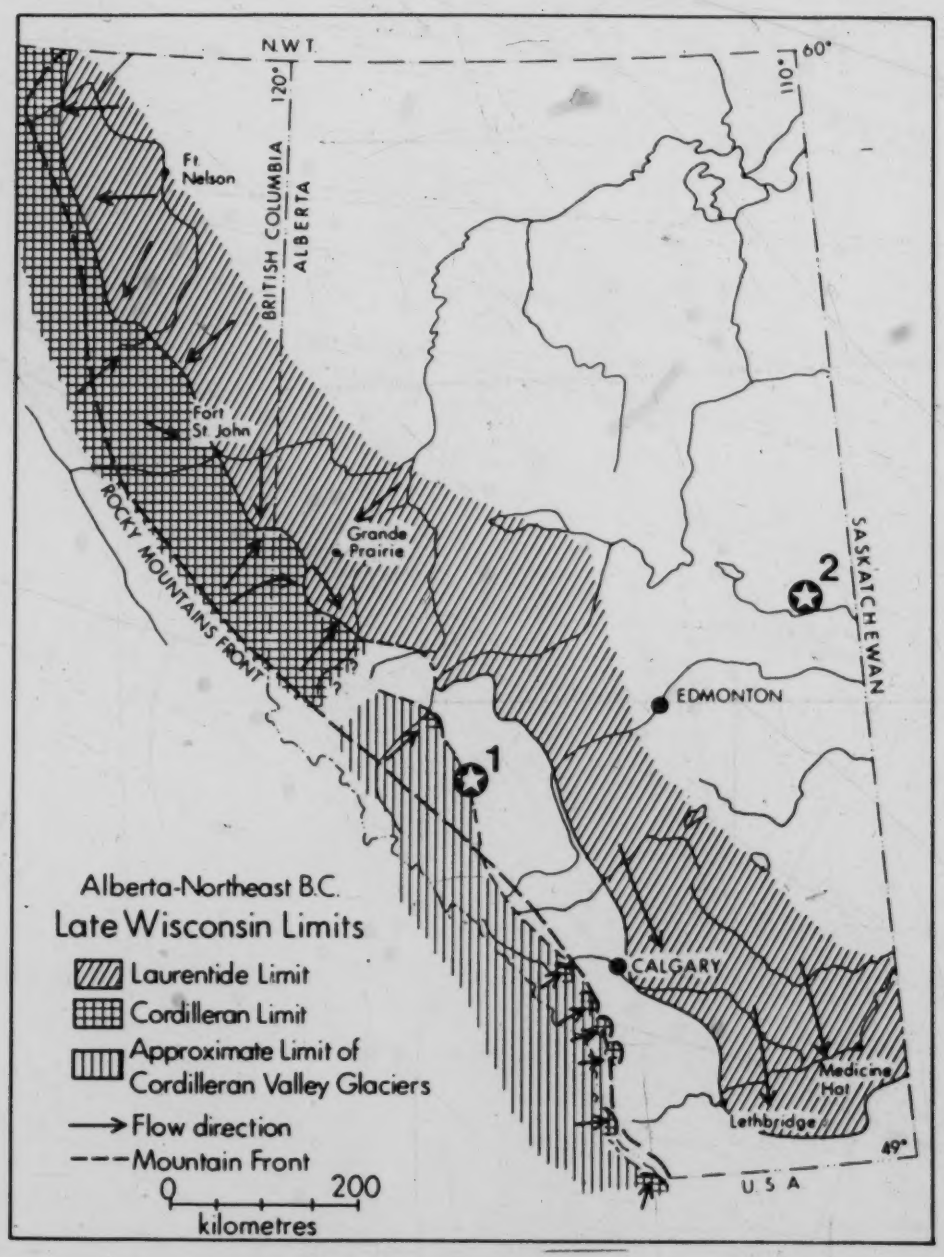

Figure I-1. Location of study sites at Muskiki Lake (1) and Marguerite Lake (2) peatlands, Alberta. (Adapted from Rutter, 1980)

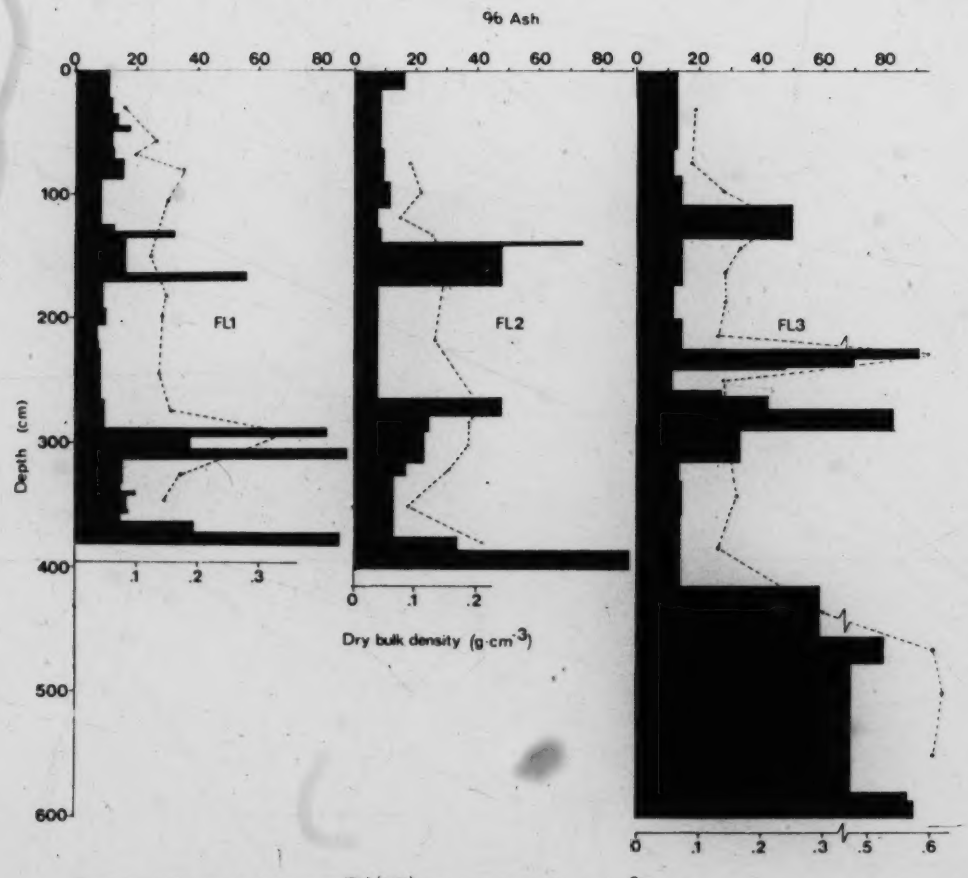

Figure I-2. Changes in ash content (%) (■) and dry bulk density ($g \cdot cm^{-3}$) (- - -) with peat depth at microsites FL1, FL2, and FL3 at Muskiki Lake peatland.

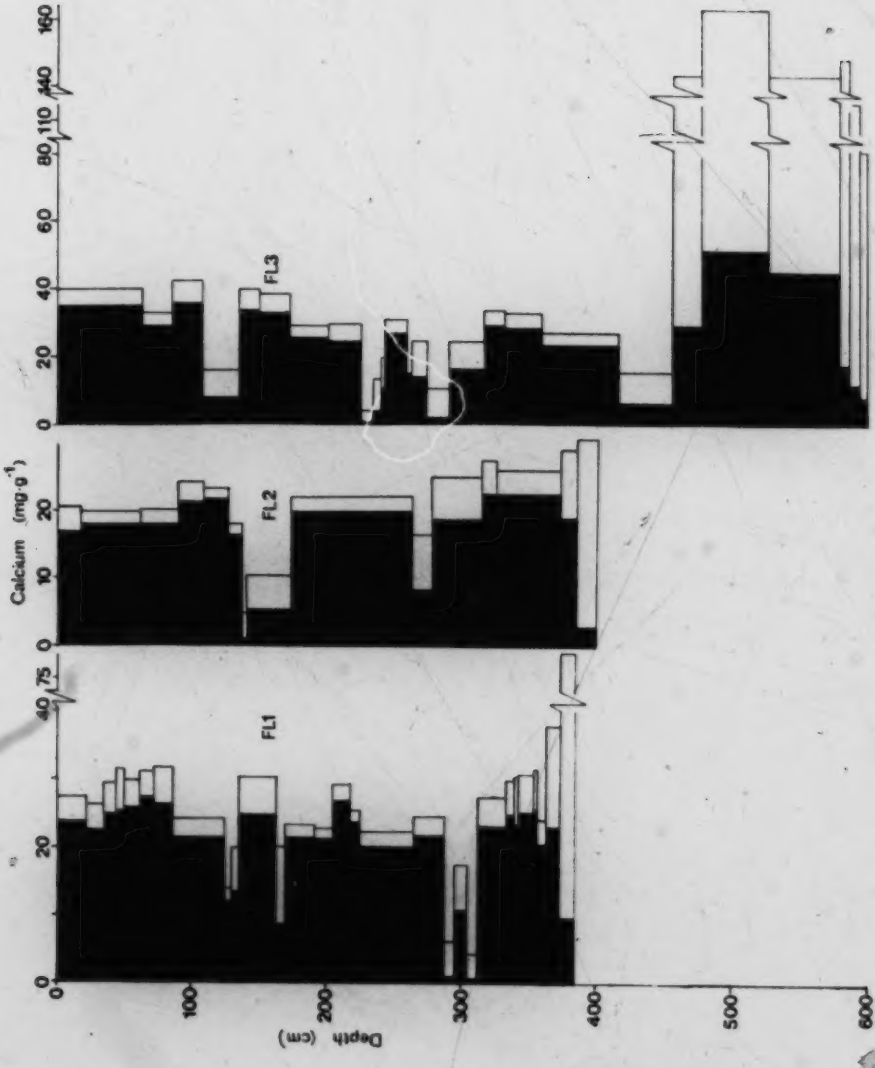

Figure 1-3. Changes in calcium (Ca^{+2}) concentration (□ total ■ ash-free) with depth at microsites FL1, FL2, and FL3 at Muskiki Lake peatland.

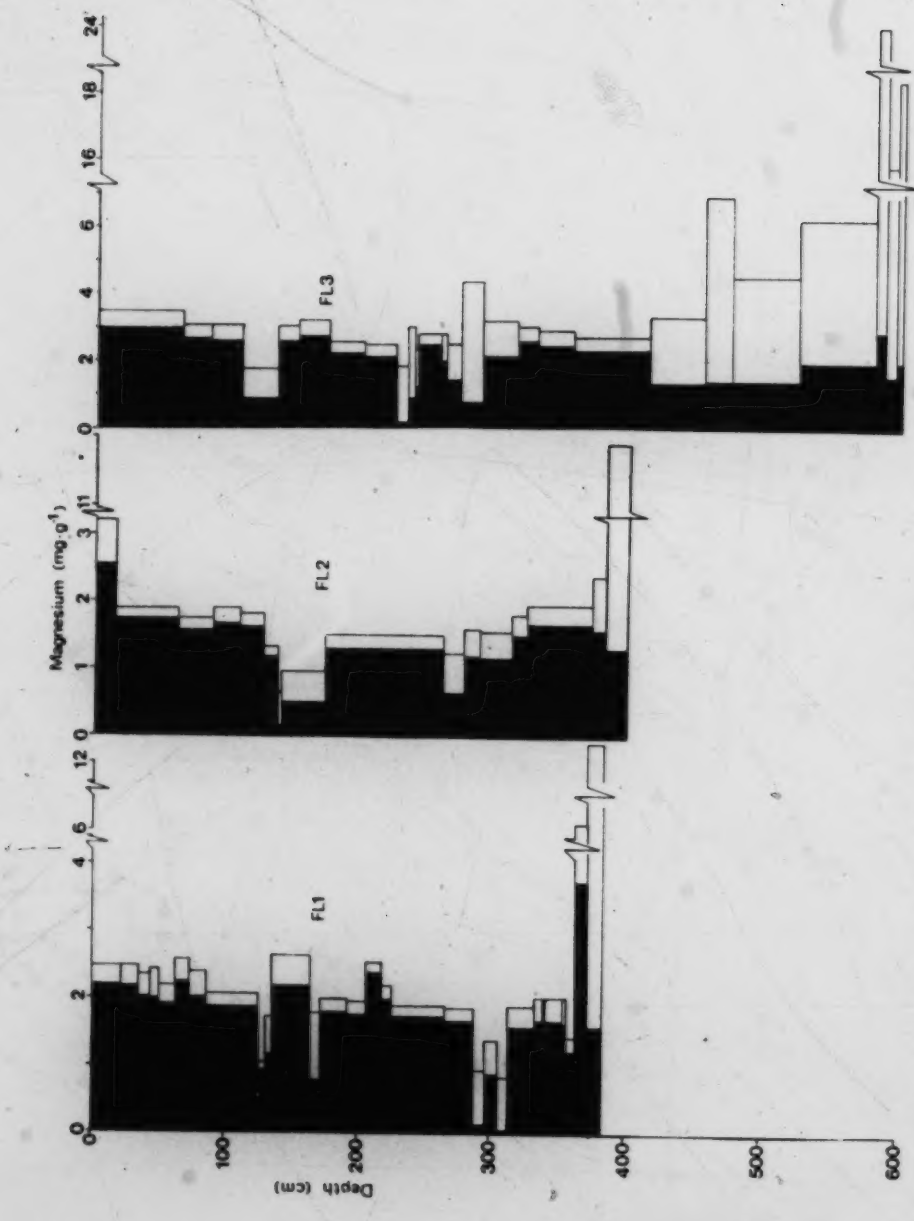

Figure I-4. Changes in magnesium (Mg^{+2}) concentration (□ total, ■ ash-free) with depth at microsites FL1, FL2, and FL3 at Muskiki Lake peatland.

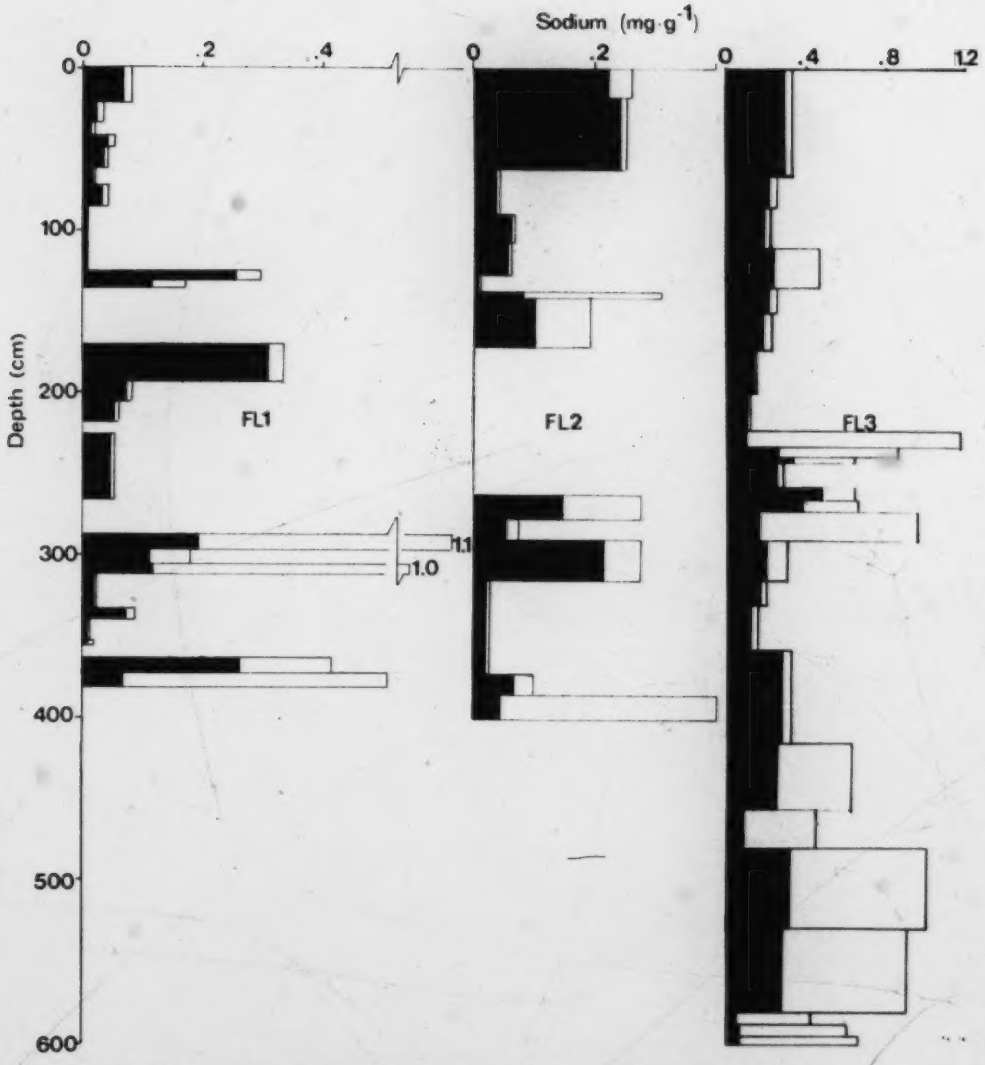

Figure I-5. Changes in sodium (Na^+) concentration (▭ total, ■ ash-free) with depth at microsites FL1, FL2, and FL3 at Muskiki Lake peatland.

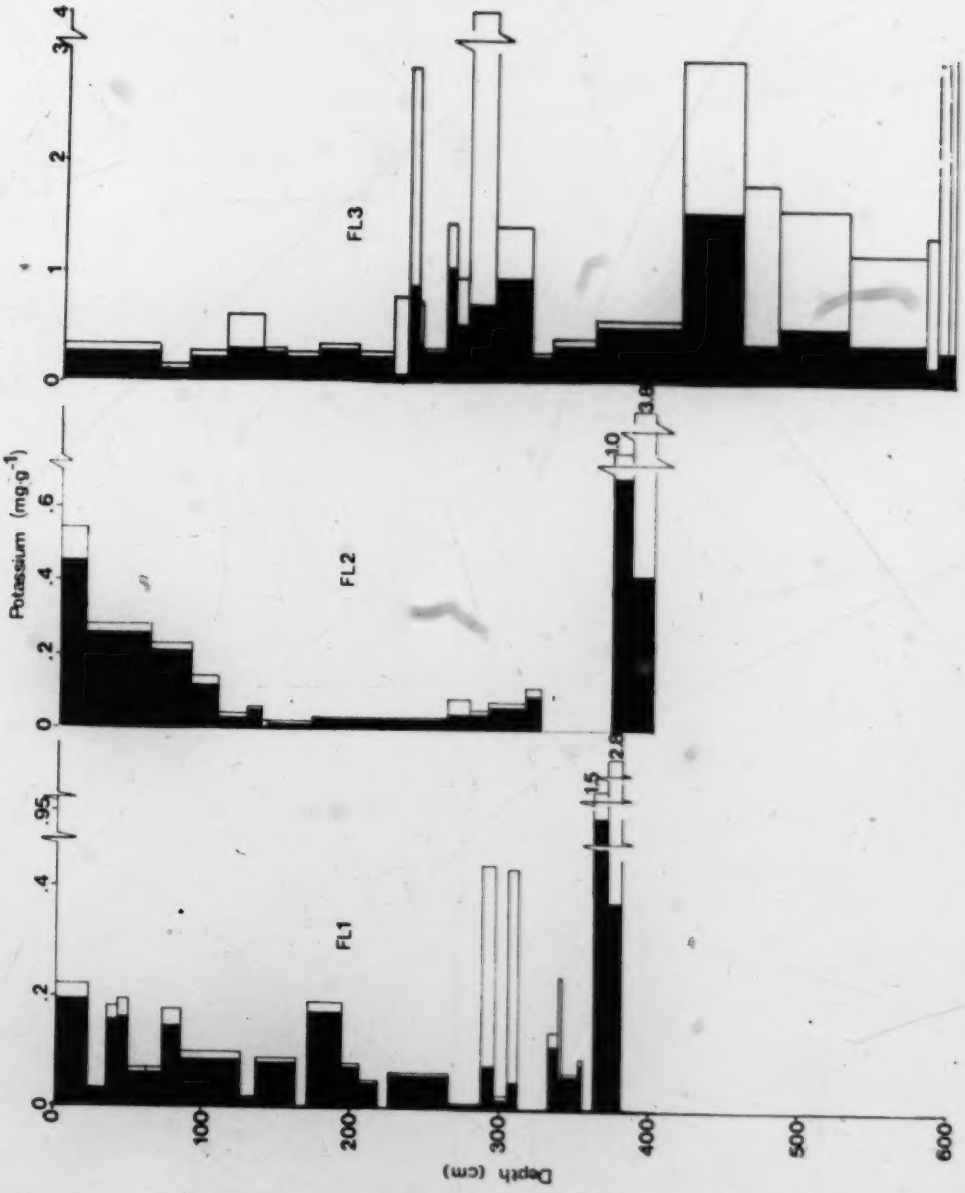

Figure I·6. Changes in potassium (K^+) concentration (□ total, ■ ash-free) with depth at microsites FL1, FL2, and FL3 at Muskiki Lake peatland.

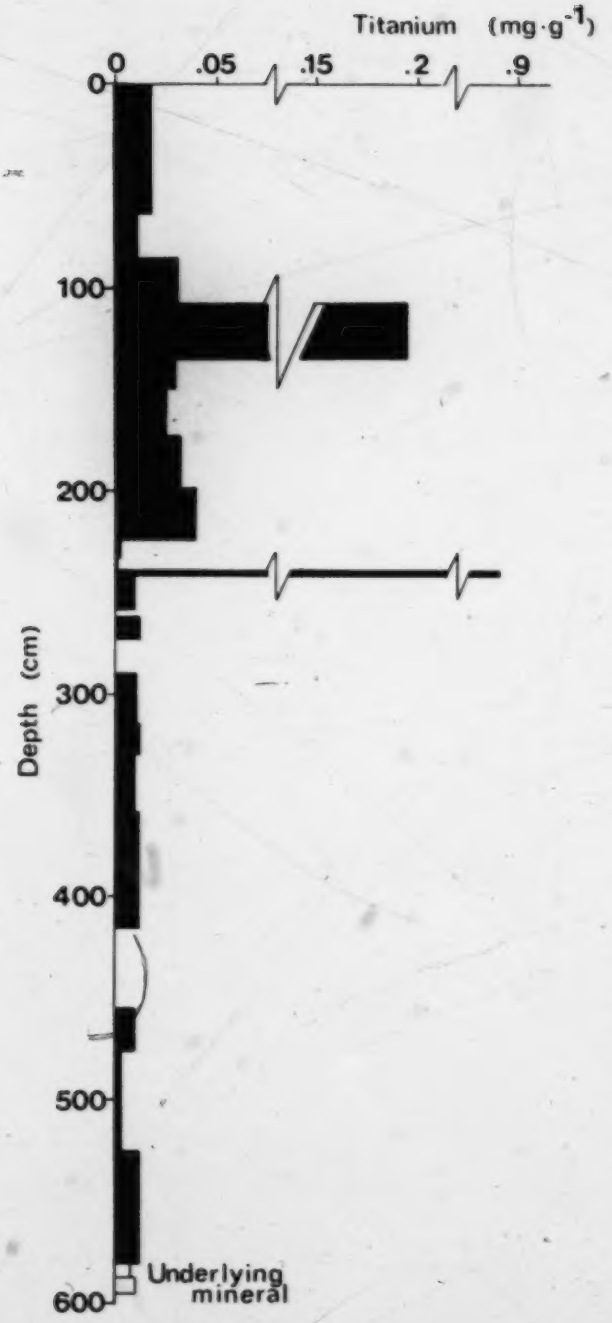

Figure I-7. Changes in titanium (Ti^{+}) concentration with depth at microsite FL3 at Muskiki Lake peatland.

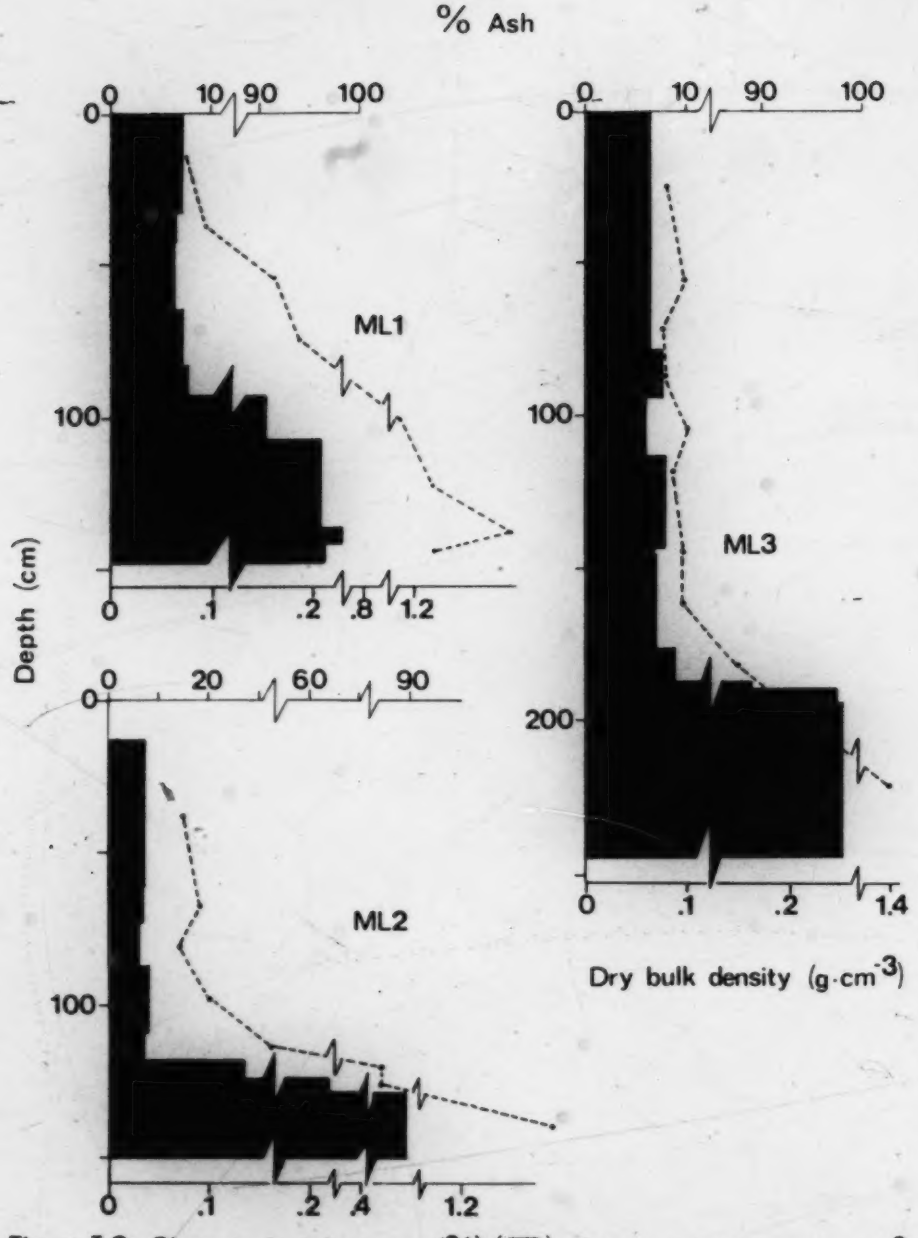

Figure I-8. Changes in ash-content(%) (■) and dry bulk density ($g \cdot cm^{-3}$)(- - -) with peat depth at microsites ML1. ML2, and ML3 at Marguerite Lake peatland.

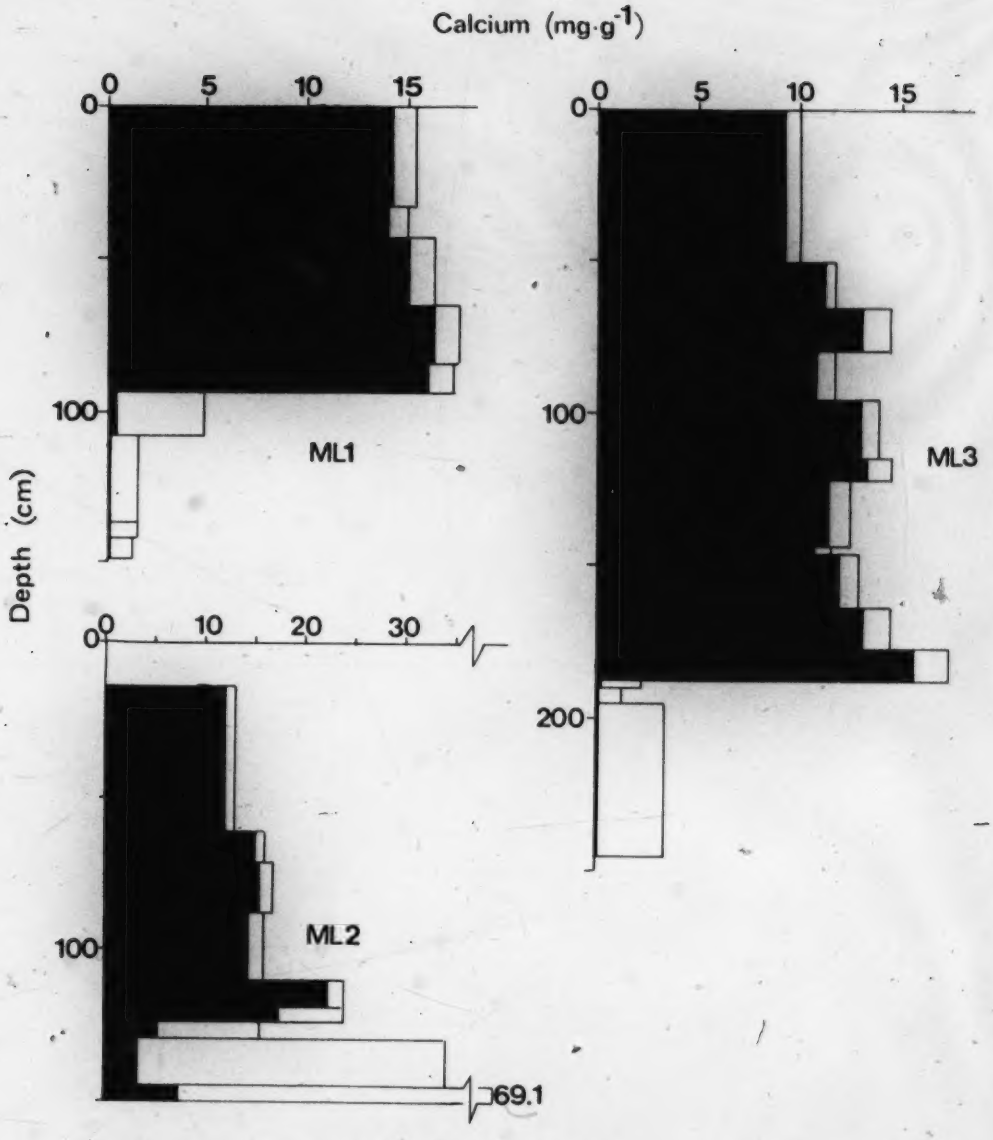

Figure I-9. Changes in calcium (Ca^{+2}) concentration (▭ total, ■ ash-free) with depth at microsites ML1, ML2, and ML3 at Marguerite Lake peatland.

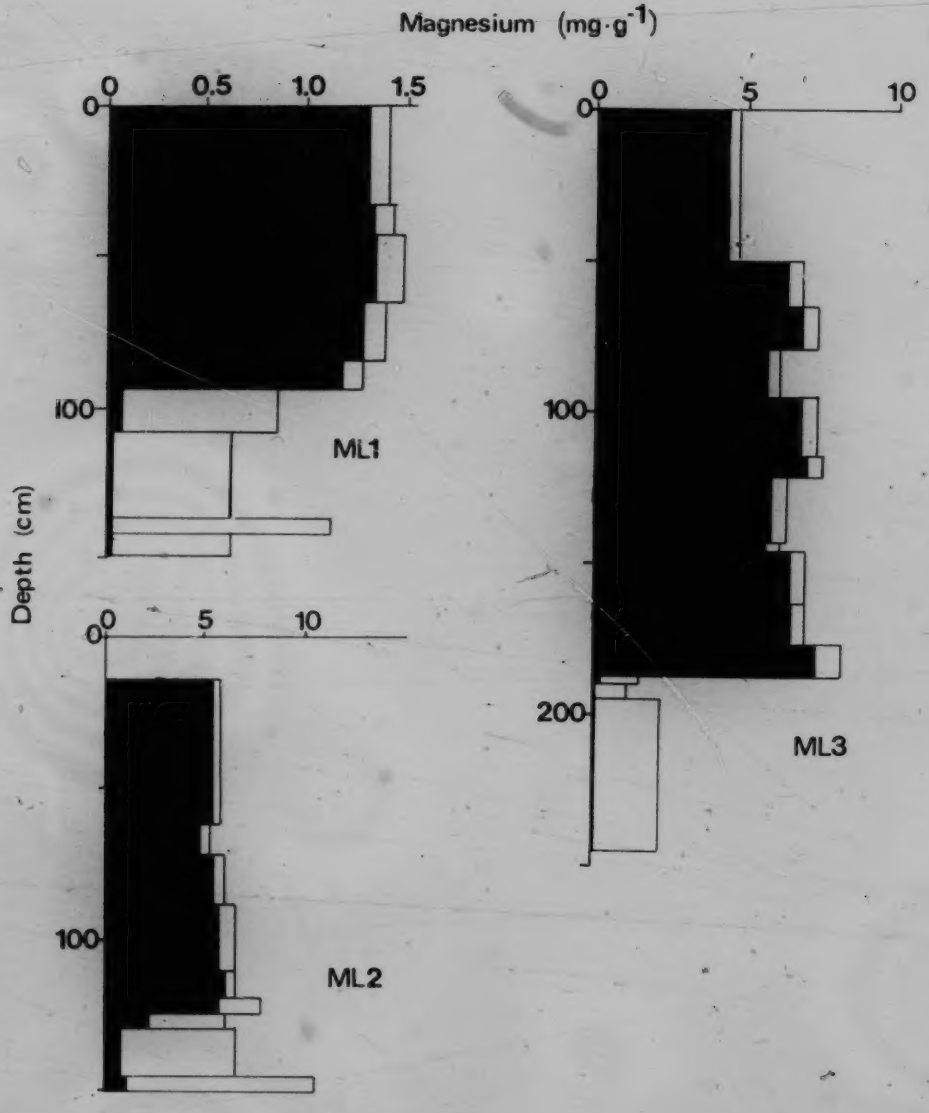

Figure I-10. Changes in magnesium (Mg^{+2}) concentration (▭ total, ▬ ash-free) with depth at microsites ML1, ML2, and ML3 at Marguerite Lake peatland.

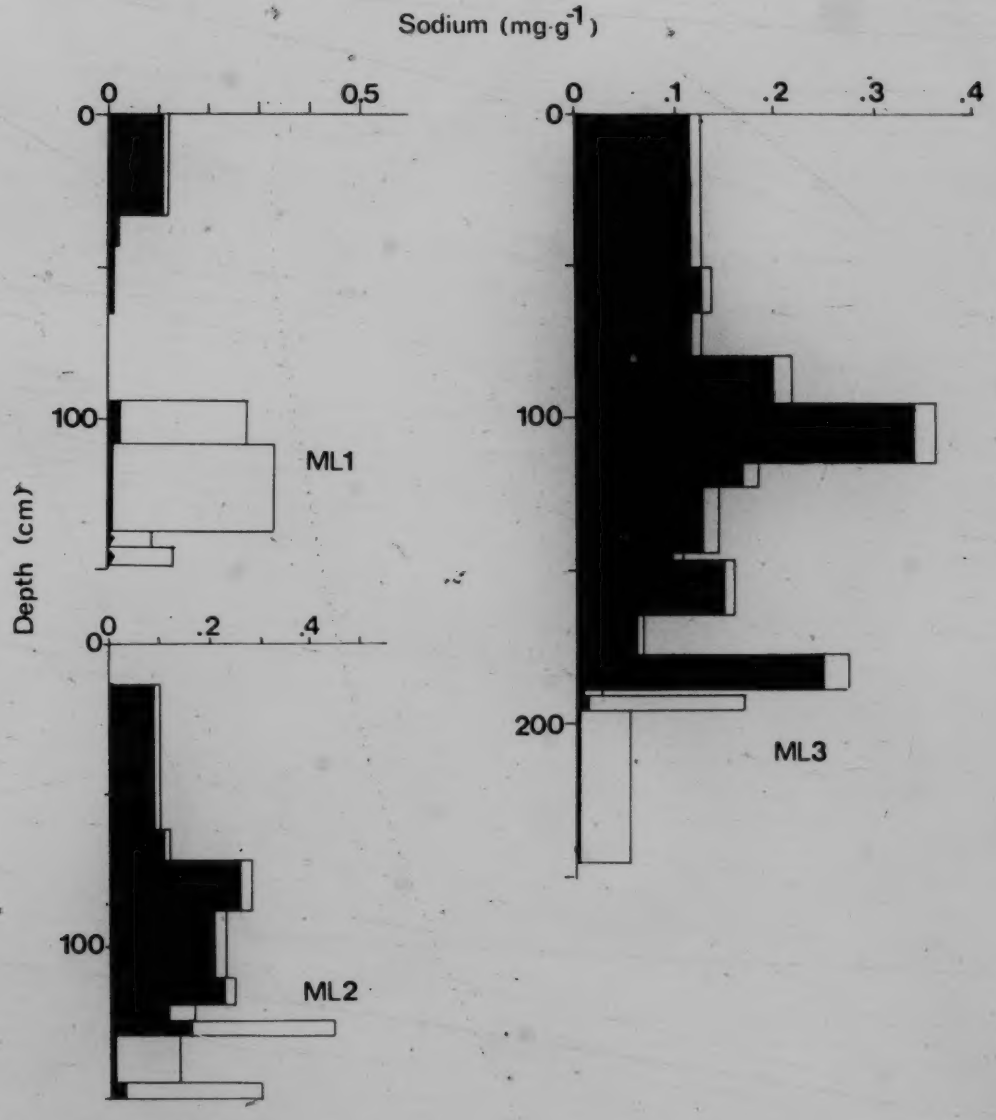

Figure I-11. Changes in sodium (Na^+) concentration (▭ total, ■ ash-free) with depth at microsites ML1, ML2, and ML3 at Marguerite Lake peatland.

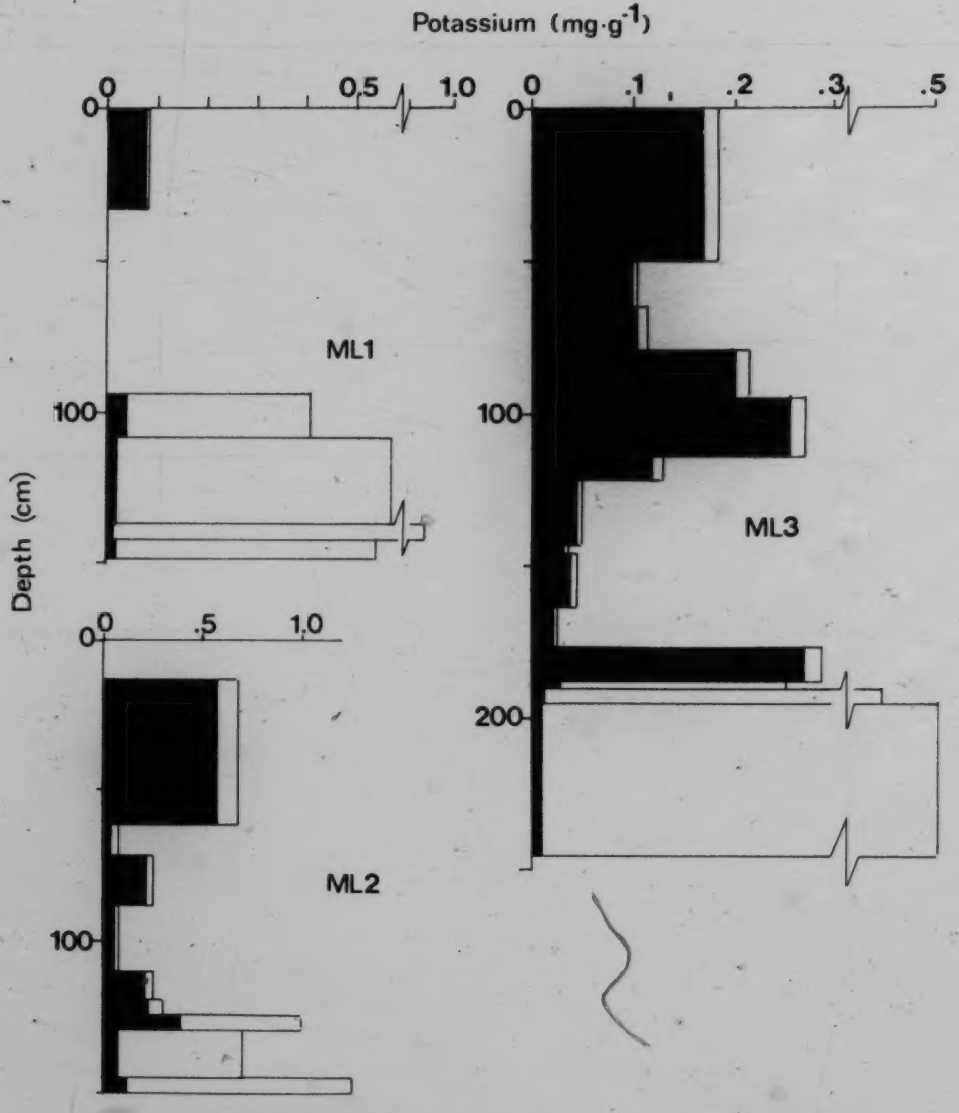

Figure I-12. Changes in potassium (K^+) concentration (□ total, ■ ash-free) with depth at microsites ML1, ML2, and ML3 at Marguerite Lake peatland.

Plate I-1. Aerial photograph of Muskiki Lake peatland. Scale 1:12,000, north is to the top-left of the photo. Microsites FL1, FL2, and FL3 are indicated.

Plate I-2. Aerial photograph of Marguerite Lake peatland. Scale 1:30,000, north is to the top of the photo. Microsites ML1, ML2, and ML3 are indicated.

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3. The developmental histories of peatlands at Muskiki and Marguerite Lakes, Alberta, Canada

3.1 Introduction

Peatlands are typically defined as unbalanced systems in which the rate of production of organic matter by living organisms is greater than the rate of their removal from the system via respiration and decomposition (Moore and Bellamy, 1974). As a result, peat, which is an accumulation of organic matter, forms.

A wealth of information regarding the provenance of a peatland and its developmental sequence lies within the peat itself. As most peats remain stratified in the sequence in which they are laid down (Moore and Bellamy, 1974), the peat stratigraphy houses a sequential record of the past vegetation. Furthermore, due to slow or even no decomposition, there are fewer uncertainties regarding the nature of these assemblages. The preservation of microfossils (pollen) and plant macrofossils (bryophytes, seeds, needles, wood, and plant fragments) in peat is often exceptional, and the likelihood of disturbance and redeposition is less probable (Oldfield, 1970) compared to lacustrine deposits.

Peatlands, though long regarded as buffered ecosystems (Moore and Bellamy, 1974), are dominated by plant species with specific environmental requirements. Various environmental factors will affect species composition and

dominance, including pH, moisture availability, temperature, and nutrient availability. As species will respond to environmental changes, the species composition should be a reflection of the local environment. When these species are incorporated into the peat, the peat deposit will retain a direct record of vegetation change. By extrapolation, the peat stratigraphy can reflect local environmental and/or macroclimatic changes that have affected this ecosystem in the past. Furthermore, since changes in the environment, both local and regional, have occurred in the past, and will occur in the future, it is essential to examine how the peatland has responded to these changes.

Examination of peatland development and the factors which affect the developmental process is not a new field of research. In the nineteenth century, initial observations regarding the filling-in of lakes with peat, and the associated floristic successions, were made (see review by Gorham, 1957). These initial observations have led to numerous attempts at developing a theory of hydroseral development (Transeau, 1903; Cooper, 1913; Dachnowski, 1924; Rigg, 1925; Frolik, 1941; Dansereau and Segadas-Vianna, 1952; Spence, 1964; Tallis, 1973). This succession requires a reduction in open water, with a subsequent build-up of peat, such that its surface eventually becomes raised above the water level (Walker, 1970). Similar sequences from open water and aquatics, to sedge mat, bog shrub, and bog forest seem to be fairly prevalent in Great Britain, although the

evidence indicates that there is no preferred pathway of hydroseral succession (Tallis, 1983). The difficulties associated with typifying the specific vegetation changes associated with the hydrosere result from the complexity of both internal and external influences on the ecosystem.

Although many peatlands can be associated with lakes, thereby implying a hydrosere, peatlands can also develop either via paludification or primary peat formation. Paludification is essentially the formation of peat on moist, previously forest-covered, low-lying land (Sjors, unpubl.). K. Tolonen's (1967) examination of peatlands in southeastern Finland revealed that most of these minerotrophic wetlands developed directly onto woodland stands above glacial sediments. Similarly, in Britain (Pearsall, 1956) and in Alaska (Heilman, 1966), the degeneration of forest communities occurred with the supercession of *Sphagnum*. Primary peat formation involves the invasion of peat-forming vegetation directly onto unvegetated moist or wet mineral soil (Sjors, unpubl.). It is believed to be a common occurrence on flatbeds and deltas, and areas of upheaval from the sea, such as the Hudson Bay and James Bay coastal areas (Sjors, 1959).

Palaeoecological studies regarding the origins and development of Albertan peatlands have emphasized both lake-filling (=terrestrialization) (Lewis and Dowding, 1926; Moss, 1953), and paludification (Hansen, 1952). These early studies, although rather descriptive and speculative due to

the lack of quantitative data (including radiocarbon dates), suggested possible developmental sequences for these peatlands, and the factors which may have affected them. Lewis and Dowding (1926) emphasized the constant association of peat areas, or muskegs, with lakes, such that with their own examination of peatlands throughout Alberta, Lewis *et al*. (1928) were able to describe several primary successions, particularly as were evident around lake margins. The main bog sere for some northwestern Alberta bogs was also described by Moss (1953). Hansen's (1952) peat studies in the Grande Prairie-Lesser Slave Lake area of Alberta emphasized moisture and permafrost as possible factors influencing the development of the peatlands on flat terrain. Moreover, he validly speculated that a warm, dry climatic maximum may have prevented earlier peat formation.

Knowledge of the origin of a peatland does not necessarily determine its developmental pattern, although it is safe to assume that the succession will be influenced by the type of origin. Certain pathways of change may occur more frequently than others. However, consideration of all factors will not permit the establishment of a "typical" sequence of peatland development, since the ways in which these environmental factors condition peatlands are very complex (Vitt and Slack, 1975). Therefore, it is essential to attain a greater understanding of the local and regional processes of peatland development, and the environmental factors involved.

In this study, the objectives were to: 1) examine the developmental histories of two peatlands in central Alberta; and, 2)attempt to determine the factors, both external and internal, which have influenced the developmental sequences. Furthermore, an attempt was made to determine the rates of development, using radiocarbon dating.

3.2 Study Sites

The study sites at Muskiki Lake (52°50'N, 116°51'W) and Marguerite Lake (54°38'N, 119°43'W), Alberta, have been described previously (Chapter I).

3.3 Methods

Peat cores in 50 cm lengths were recovered from three microsites within each peatland, using a modified McCauley peat sampler with an inside diameter of five cm. Upon extraction, the peat cores plus some underlying mineral soil were wrapped in cellophane, labelled, and stored in PVC pipes for transport. The cores were stored at 2°C.

Quantitative macrofossil analyses followed Janssens (1983). For each horizon identified in the core, at least one sample was recovered, and its volume determined by displacement. Before processing, approximately 0.5 g of poppy seeds was added to each sample, in order to later calculate macrofossil concentrations, based on sieved samples. Calibration of poppy seed weights, by counting the number of grains in known weights, indicates that 0.5 g of

poppy seeds contains 1980±64 grams, according to the linear relationship:

#grams = 2050.6(weight)-12.86

Each sample soaked for at least three days in distilled water to which a few drops of a non-foaming wetting agent (areosol OT (75%)), had been added. After gently washing the sample through 500 um and 100 um sieves, a small amount of peat retained on the larger mesh was placed in a shallow trough dish with distilled water, and examined under a dissecting microscope.

All macrofossils were counted and measured, until a total of at least 10 poppy seeds was counted. Moss stems and wood, sedge, charcoal, and needle fragments were measured on a millimeter basis. Needle fragments were subsequently converted to a total number, based on the length of modern needles. Furthermore, individual moss leaves were counted and subsequently converted to a stem measurement (nm) by dividing the number of leaves by fifty for *Sphagnum* and by five for the other mosses. Voucher slides which were made of all macrofossils are deposited at the University of Alberta Cryptogamic Herbarium. Identification of macrofossils, particularly bryophytes, were confirmed by comparison with modern and subfossil reference material at the University of Alberta. Authority names follow Moss (1983) for vascular plants, and Ireland *et al.* (1980) for mosses.

Based on volume determinations, poppy seed counts and macrofossil measurements, macrofossil concentrations (mm

stem/ml, for bryophytes; mm/ml or #/ml for all other plant materials) were calculated. The use of absolute macrofossil concentrations may eliminate the over-representation of certain species which could mask actual changes in vegetation. Macrofossil diagrams were drawn for each peat core, based on the changes in species composition and concentrations with depth. After each diagram was constructed, local peat zones were delineated based on differences with respect to the composition and frequencies of the macrofossils present. Associations of bryophytes of similar modern autecologies were also considered in the delineation of zones.

3.4 Results

3.4.1 Muskiki Lake Peatland

3.4.1.1 Microsite FL1

Six local peat zones are delimited in this 370 cm peat core from the string at microsite FL1 (Figure II-1).

Zone FL1-A (333.5-370 cm) lies above an impermeable blue-gray glaciolacustrine clay. A basal date at sampling level 361-368 cm indicates that initial peat formation at FL1 began about 8480±190 ^{14}C years ago (AECV #206C).

The abundance of wood, twig, and bark fragments in these lowermost sampling levels, primarily 363-370 cm,

indicates that the area was forested when initial peat formation began. The particular species present as well as the needle fragments suggest a forest, rather than a thicket. Subsequently, the virtual absence of arboreal macrofossils with an increase in *Sphagnum* suggests that this forested site was subsequently encroached upon by *Sphagnum*. Although the preservation made determination of *Sphagnum* species difficult, *S. angustifolium* and *S. warnstorfii* were identified. Other determinations could only be made to *S.* sect. *Acutifolia* and *S.*sect. *Cuspidata*. Fragments of *Polytrichum strictum* are also present.

The rapid transition from *Sphagnum* to the sedges and brown mosses marks the onset of zone FL1-B (221-333.5 cm). A radiocarbon date at sampling level 313-322 cm indicates that this change in vegetation occurred shortly before 7080±150 years ago (AECV #198C). This date is corroborated by the presence of Mazama tephra at a depth of 288-293 cm. This tephra is dated at about 6600 years ago (Westgate *et al.*, 1969). The increase in sedge fragments and such hydrophilic bryophytes as *Campylium stellatum*, *Calliergon richardsonii*, *C. stramineum*, *Drepanocladus revolvens*, *Scorpidium scorpioides* and *Meesia triquetra* (Richt.) Angstr., is interpreted as representing an open-water, sedge meadow. A significant wood component of bark, twigs, wood and *Picea* needles suggests an arboreal

response to a rising water table, although a lag in time would have occurred between the increased wetness, the response of the trees, and the incorporation of wood into the peat.

The increase in concentrations of mosses other than of the Sphagnaceae and Amblystegiaceae marks the onset of zone FL1-C (171-221 cm) about 4500 years B.P. *Tomenthypnum nitens* becomes the dominant bryophyte. *Paludella squarrosa* (Hedw.) Brid. is also an important component of this zone. Although several brown mosses, such as *Drepanocladus* and *Scorpidium* are present in this zone, their concentrations have decreased substantially from zone FL1-B, and *Sphagnum* has virtually disappeared.

After the deposition of St. Helens Y tephra at 162-170 cm depth about 3700 years B.P. (Hickman *et al.*, 1978), *Sphagnum* reappears as the dominant in zone FL1-D (119-171 cm). The date of this zone change is corroborated by a radiocarbon date of 3670±150 years B.P. (AECV #205C) at 172-180 cm. Most of the *Sphagnum* in this zone comprises of *S.* sect *Acutifolia*. *S. warnstorfii* is the dominant species, although *S. nemoreum* and *S. fuscum* are also present. *Picea mariana*, as represented by wood and needles, is also an important component of this zone.

Zone FL1-E (63.5-119 cm) is a short-lived reversal to brown mosses and sedges about 2760±100 years B.P. (AECV #204C). The return of the hydrophilic species of

Scorpidium scorpioides and *Drepanocladus revolvens* suggest increased wetness.

Zone FL1-F (0-63.5 cm) is the uppermost peat zone, and is reflective of the present-day vegetation of this string. *Sphagnum fuscum* and *S. warnstorfii* are the dominant species of this zone. Other bryophytic species present include *Polytrichum strictum*, *Tomenthypnum nitens*, and *Pohlia nutans* (Hedw.) Lindb. which are all species of drier habitats. Although several brown moss species are still present in the lowermost portions of this zone, their concentrations are very low. Roots, both woody and herbaceous, make up a significant component of this local peat zone.

3.4.1.2 Microsite FL2

Five local peat zones are delineated in a 364 cm peat core from the flark at this microsite (Figure II-2).

The lowermost peat zone, zone FL2-A (295-364 cm), is a *Sphagnum*-dominated peat with a significant wood layer directly above a gray clay with stone inclusions. A basal date at 351-364 cm depth indicates that peat initiation began about 7850±400 years B.P. (AECV #129C). The wood layer indicates that peat formation at this microsite was directly onto forested dry land. Charcoal at the top of this zone (320-325 cm) is indicative of fire activity.

The onset of zone FL2-B (195-295 cm) at about 6320±290 years B.P. (AECV #209C) is marked by the drastic reduction in *Sphagnum* and the virtual absence of most mosses. Members of the Cyperaceae are the dominant component of this zone, and continue to be a significant component throughout the peat core.

Zone FL2-C (134-195 cm) marks the onset of flark differentiation which is dated at about 4600±110 years B.P. (AECV #208C). Although the Cyperaceae remain a dominant component of this zone, the brown mosses, particularly *Calliergon stramineum* and *Scorpidium scorpioides*, become an important part of the vegetation.

Zone FL2-D (100-134 cm) is characterized by an increase in *Sphagnum* and the reappearance of other mosses including *Tomenthypnum nitens*, *Meesia triquetra*, and *Bryum pseudotriquetrum* (Hedw.) Gaertn., Meyer, & Scherb. This narrow zone is short-lived, before the brown mosses and sedges return to dominance in zone FL2-E (0-100 cm).

Zone FL2-E is the uppermost peat zone which comes in about 3300±100 years B.P. (AECV #207C). *Scorpidium scorpioides* is the dominant bryophyte. Other bryophytes present include *Drepanocladus revolvens*, *Calliergon richardsonii*, *C. giganteum*, *C. stramineum*, *Meesia triquetra*, and *Bryum pseudotriquetrum*. *Equisetum fluviatile* is also an important component here.

3.4.1.3 Microsite FL3

Five local peat zones are identified in a 525 cm peat core from this microsite (Figure II-3).

The macrofossils of the lowermost zone (zone FL3-A; 456-525 cm) indicate the lacustrine origin of this site. Although very few identifiable macrofossils are present in this amorphous gyttja and aquatic peat, sedges, *Chara* oogonia, and fragments of mosses including *Drepanocladus exannulatus* (B.S.G.) Warnst. and *Meesia triquetra* were identified. The presence of *Chara*, *Meesia*, and *Drepanocladus* is indicative of the calcareous nature of this zone. *Chara* and *Drepanocladus exannulatus* suggest that peat accumulation began in the lake and around lake margins, although it is unlikely that true peatland formation began before zone FL3-B.

Zone FL3-B (325-456 cm) is dominated by the brown mosses, including *Scorpidium scorpioides*, *Drepanocladus revolvens* and *Calliergon richardsonii*. The autecologies of these species suggest that this zone is representative of a very wet, calcareous peatland of very high pH (Janssens, 1981). A radiocarbon date at 450 cm indicates that this zone began about 9000±230 years B.P. Drier conditions previously recorded in the foothills about 9000 years ago (Schweger *et al.*, 1981) were probably sufficient to reduce lake levels at Muskiki Lake such that peat formation could begin.

Zone FL3-C (190-325 cm) is marked by the significant absence of the brown mosses and the sudden appearance of *Sphagnum* and other mosses. Dominant mosses in this zone are *S. warnstorfii* and other *S.* sect. *Acutifolia* (indeterminable to species), *Paludella squarrosa*, *Tomenthypnum nitens* and *Aulacomnium palustre*. Abundant remains of wood, twigs and bark are mixed with the peat, particularly at sampling level 278-282 cm. A radiocarbon date of 4910±200 years B.P. at 210-219 cm and the presence of Mazama tephra (235-255 cm) would probably place the boundary of zones FL3-B and FL3-C at about 7200 years B.P.

Zone FL3-D (100-190 cm) is a narrow zone characterized by the return of the brown mosses such as *Scorpidium scorpioides* and *Drepanocladus revolvens* about 4500 years B.P. Although *Sphagnum warnstorfii*, species of *S.* sect. *Acutifolia*, *Tomenthypnum* and *Paludella* are still present, their concentrations are much reduced in this zone.

The uppermost peat zone, zone FL3-E (0-100 cm), resembles zone FL3-C, with dominant macrofossils of *Sphagnum warnstorfii*, *S.* sect. *Acutifolia* and *Tomenthypnum nitens*. The brown mosses are absent from this zone. The reappearance and increased concentrations of *Tomenthypnum* and other species suggest drier conditions.

3.4.2 Marguerite Lake

3.4.2.1 Microsite ML1

The three peat cores from Marguerite Lake peatland are much shallower than at Muskiki Lake peatland, ranging from 124.5 cm to 194 cm. The shallowest peat depth (124.5 cm) was recorded at microsite ML1 (Figure II-4). Only two local peat zones were delineated in this peat core.

Zone ML1-A (96-124.5 cm) is the lowermost zone, and is defined by a charcoal layer just above the underlying mineral soil of coarse sand and gray-green clay. The presence of wood and charcoal, and the paucity of bryophytes indicates that this microsite was initially forested, and thus, peat formation began via paludification. Due to problems encountered during the processing of the basal peat for radiocarbon dating, a basal date for the onset of peat accumulation is unavailable. However, extrapolation from a radiocarbon date at sampling level 60-72 cm and from rates of peat accumulation from microsites ML2 and ML3 (Table II-2) suggests a date of about 2400 years B.P.

An abundance of charcoal, indicative of fire activity, at sampling levels 96-103.5 cm, marks the beginning of zone ML1-B (0-96 cm). Bryophytes such as *Drepanocladus aduncus* (Hewd.) Warnst. and sedges come into prominence in this zone. The abundance of *Larix* needle fragments cooroborates the arboreal element of

this vegetation, as first indicated by the increasing concentrations of wood fragments. Many bryophytic species first come into prominence at the top of the peat column. These include *Meesia triquetra*, *Campylium polygamum* (B.S.G.) C. Jens., *Tomenthypnum nitens*, and *Drepanocladus revolvens*.

3.4.2.2 Microsite ML2

Three local peat zones are identified in this 132 cm core from microsite ML2 (Figure II-5).

Similar to zone ML1-A, the presence of charcoal and the scarcity of bryophytes in the lowermost zone at microsite ML2 (zone ML2-A; 105-132 cm) indicates a forested area, which included *Larix laricina* and which was subsequently burnt. A basal radiocarbon date at sampling level 117.5-124 cm just above the underlying clay indicates that peat accumulation began about 2750±150 years B.P. (AECV #202C). Members of the Cyperaceae, and the brown moss *Drepanocladus revolvens* are the dominant vegetation components of this zone. The dominance of the sedges and this brown moss suggests a high water table, which may have been the result of a severe burning.

Zone ML2-B (74-105 cm) is a narrow zone marked by the increase in concentration of another brown moss, *Scorpidium scorpioides*. *Drepanocladus revolvens* is still present, although its concentration begins to decrease in this zone. Other bryophytes present include *D.*

aduncus and *Bryum pseudotriquetrum*. Needles of *Larix* are found throughout this zone.

This short-lived zone gives way to zone ML2-C (0-74 cm), the beginning of which is dated at about 1810 ±100 years B.P. (AECV #201C). Zone ML2-C is dominated by several calciphilic bryophytes, including *Scorpidium*, *Drepanocladus revolvens*, *Campylium polygamum* and *Calliergon richardsonii*. Sedges increase in concentration in this zone. Wood fragments (*c.f. Betula*) are an important component of the uppermost peat.

3.4.2.3 Microsite ML3

The 194 cm core from microsite ML3 is divided into three local peat zones (Figure II-6).

The lowermost zone, zone ML3-A (157-194 cm), is a humified peat zone which lies directly above the light brown and dark gray-brown sand horizons. Although sedges, brown mosses and roots are a significant component of this peat zone, as they are throughout the core, zone ML3-A is defined by the presence of wood and charcoal. The wood component of this zone includes fragments of bark, twigs and wood.

Although the proximity of microsite ML3 to Marguerite Lake might suggest peat inception by lake-filling, the presence of wood and charcoal, as well as the sand horizons (typical of the surrounding uplands), suggests paludification.

The onset of zone ML3-B (66-157 cm), a wide peat zone of fibric and humic horizons, is marked by the rise to dominance of *Drepanocladus aduncus* and *D. revolvens*, indicative of wetter conditions. Although other mosses including *Scorpidium scorpioides*, *Calliergon richardsonii*, *Meesia triquetra*, and *Bryum pseudotriquetrum* are present in this zone, they generally do not rise to prominence until the subsequent, uppermost zone. A radiocarbon date at sampling level 122.5-130.5 cm indicates that the abrupt transition from the lower humic horizons to the fibric horizons above occurred about 2670±150 years B.P. (AECV #203C).

Zone ML3-C (0-66 cm) is a fibric zone defined by the rise to dominance of several wet-loving, calciphiles of the family Amblystegiaceae, particularly *Drepanocladus revolvens* and *Campylium polygamum*. Also prominent are *Scorpidium turgescens* and *Calliergon richardsonii*.

3.4.3 Rates of peat formation

Thirteen radiocarbon dates from Muskiki Lake peatland and five from Marguerite Lake peatland are listed in Table II-1.

Based on sample depths and these dates, peat accumulation rates (cm/yr) were calculated. Rates of peat accumulation at the two sites range from 0.034 cm/yr to

0.079 cm/yr. These peat accumulation rates are comparable to those of other North American (Ovenden, 1982; Zoltai and Johnson, 1985; Kratz and DeWitt, 1986) and European (Aartolanti, 1967; K. Tolonen, 1973; Aaby and Tauber, 1975) peatlands.

Due to compaction of the peat, as well as differential ash content, the net organic accumulation ($g/cm^2/yr$) was calculated, as a product of the peat accumulation rate (cm/yr) and dry bulk density (g/cm^3) (Table II-1). As net organic accumulation depends on both productivity and decomposition, this growth may be reflective of local moisture conditions, since increased wetness may promote rapid peat growth and retard decomposition. Net organic accumulation rates range from 0.005 to 0.015 $g/cm^2/yr$ (Table II-1).

3.5 Discussion

The onset of peat accumulation can be related to several factors, including deglaciation, climatic conditions, and catchment characteristics (Payette, 1984). Depending on the site, however, these and other factors may vary in their importance in peat inception. Such appears to be the case at Muskiki and Marguerite Lakes peatlands.

Muskiki Lake peatland records a basal radiocarbon date of about 9000 years B.P. Peat inception following deglaciation is suggested by this date, as deglaciation was generally completed by approximately 10,000 years ago in

Alberta (Fulton *et al.*, 1984). However, the glacial history of the Muskiki Lake area is somewhat uncertain. According to Rutter (1980), the lake and adjacent peatland may be part of the ice-free corridor, a zone of land which extends from the Arctic Ocean to the 49th parallel, along the eastern side of the Cordilleran area of the Rocky, Mackenzie, and Richardson Mountains between the Cordilleran and Laurentide ice sheets (Figure I-1). Although some researchers believe that the southern corridor may have existed since Illinoian or early- to mid-Wisconsin (Reeves, 1970), conservative estimates place the opening of this corridor at 15,000 to 20,000 years B.P. (Jackson, 1979).

If Muskiki Lake is part of this ice-free corridor, a delay of at least several thousand years may have occurred between deglaciation and peat inception at this site. Thus, the climatic conditions and the characteristics of the basin may have been critical for peat initiation at Muskiki Lake peatland. However, if this site is outside of the ice-free corridor, deglaciation would have been the factor critical to the onset of peat accumulation.

Regardless of the presence of Muskiki Lake in the ice-free corridor, and the prerequisite deglaciation for peat inception, a significant characteristic of this peatland is its duality of peat origins. There is evidence for both lake-filling (=terrestrialization) and paludification at this peatland.

At microsite FL3, which is closest to the lake, peat formation began via lake-filling about 9000 years B.P. The peat stratigraphy indicates that, previous to this date, this site was covered by shallow water, perhaps when Muskiki Lake was much larger than at present. Directly above the mineral soil, an amorphous gyttja and aquatic peat of *Chara*, sedges, and a few bryophytes, including *Drepanocladus exannulatus* and *Meesia triquetra*, suggest alkaline conditions. A reduction in Muskiki Lake's water level due to increasing drought and evaporation in the foothills about 9000 years B.P. or perhaps even earlier (Schweger *et al.*, 1981) may have helped initiate peat accumulation.

From 9000 to 7530 years B.P., however, this microsite existed as a highly calcareous fen dominated by the brown mosses. The transition from an aquatic environment to this rich fen suggests a peatland with high conductivity (alkaline), high pH, and very wet conditions. These wet conditions are corroborated by the highest net organic production (0.015 g/cm^2/yr) recorded at any site. The increased wetness would have promoted rapid peat growth and retarded decomposition, resulting in greater accumulation of organic matter.

About 8000 years B.P., conditions allowed peat inception to begin in the valley below the lake, as evidenced at the string and flark microsites. Paludification at these sites is suggested by the presence of a wood layer directly above the mineral soil, as well as by the presence

of *Sphagnum*, *Polytrichum strictum*, and *Dicranum undulatum*, typical of drier habitats. Sjors (unpubl.) suggests that paludification was a common mode of peat initiation in the boreal forest during the early Holocene, as evapo-transpiration was not so great that peat onset via paludification could be prevented.

About 7530 years B.P., local changes in moisture occurred closer to the lake. The abrupt change is marked by the virtual disappearance of the hydrophilic brown mosses, and the increasing concentrations of species of *Sphagnum*, *Aulacomnium palustre*, *Tomenthypnum nitens* and *Paludella squarrosa*.

Based on the modern habitat preferences (Janssens, 1981; Vitt and Slack, 1984) of the bryophytes found in the peat core from microsite FL3, a moisture preference value from 1 to 5 was assigned to each species (Table II-3). Aquatic and semi-aquatic bryophytes are assigned a moisture preference value of five, whereas one indicates bryophytes always found on the driest sites. At each level, for each species, this moisture preference value was multiplied by the concentration of that species at that depth. These values were added together for all species such that a moisture index for each sample depth was determined. Figure II-7 corroborates the change from wet to dry conditions after 7530 years B.P. Drier conditions may also be indicated by decreased rates of net organic accumulation, from 0.015 to 0.008 $g/cm^3/yr$.

A period of warmth and aridity during the Holocene is well-documented for Alberta and adjacent areas. Sediment cores from Fairfax and Goldeye Lakes suggest temperature increases and/or increases in aridity between 9000 and 6000 years B.P. (Schweger *et al.*, 1981). This thermal event, previously referred to as the Hypsithermal, is well-indicated at Muskiki Lake by a significant change in species composition and net organic production. It is interesting to note that many lakes (and probably many peatlands) in Alberta formed between 3000 and 5000 years ago (Schweger *et al.*, 1981). This may be due to the shallowness of most basins and the increased aridity associated with this thermal event. This may also help explain the more recent formation (3400 years B.P.) of the Marguerite Lake peatland. The Pacific moisture influence from across the Rocky Mountains was probably critical to the persistence of Muskiki Lake and its peatland through this warm, dry interval.

While species composition was changing abruptly at microsite FL3, in response to the increasing warmth and aridity, the dry-habitat bryophytes persisted at the string and flark sites, although a fire recorded at about 6800 to 7000 years B.P. marked the transition to a sedge meadow. The fire, if sufficiently severe, may have caused a rise in the water table (M. Tolonen, 1985). As no charcoal was observed at microsite FL3, however, the fire was perhaps local. A more plausible explanation suggests that an obstruction,

probably a beaver damming, may have impeded drainage and increased wetness at the string and flark sites such that the brown mosses and sedges could increase in abundance.

One of two volcanic ashes found in the Muskiki Lake peat cores occurs in the interval marked by this thermal event. Mazama tephra, dated at about 6800 years B.P. (Bacon, 1983), is an important chronostratigraphic marker which allows correlation between all cores at this peatland, as well as corroborating radiocarbon dates. The second tephra, St. Helens Y (about 3500 years B.P.) (Westgate *et al.*, 1969), is found in the uppermost 150 cm of each peat core from Muskiki Lake. These volcanic ashes can be used as time-synchronous planes. If we assume that the base of each volcanic ash was deposited at approximately the same time at each microsite, it is possible to correlate the vegetation of this peatland at three times in its history: (1) the present; (2) the time of St. Helens Y volcanic ash deposition; and (3) the time of Mazama ash deposition (Table II-4).

Table II-4 and Figure II-8 correlate the peat stratigraphies at microsites FL1, FL2, and FL3, based on the initial deposition of the volcanic ashes. All ash horizons were visible in the field, except for St. Helens Y ash at microsite FL3. This tephra was distinguished via titanium and ash content in the lab. As the thickness of this ash deposit is uncertain, the upper and lower limits of the sample horizon are indicated. Figure II-8 indicates the

variability of the peatland surface, both with respect to vegetation and topography.

At the time of Mazama ash deposition, about 6800 years B.P. (Bacon, 1983), microsite FL3 was dominated by *Sphagnum*, whereas microsites FL1 and FL2 were sedge areas, which had recently been *Sphagnum*-dominated. Then, at the time of deposition of St. Helens Y tephra (3500 years B.P.) (Westgate *et al.*, 1969), brown mosses dominated the vegetation at microsites FL2 and FL3. Microsite FL1's vegetation consisted of bryophytes such as *Tomenthypnum*, *Paludella*, and brown mosses, including *Scorpidium* and *Drepanocladus*. Since the deposition of St. Helens Y, these three microsites have undergone several vegetation changes before establishing themselves as a *Sphagnum-Picea* string (FL1), a brown moss flark (FL2), and a hummocky-hollow fen of *Sphagnum*, *Tomenthypnum*, *Picea* and sedges.

It is interesting to note the differences in thickness of the ash horizons at these three microsites, which may be a function of peat accumulation and ash compaction. Furthermore, at microsites FL1 and FL3, two separate horizons of Mazama ash are evident. As reworking and redeposition of the ashes is unlikely in peatlands, compared to lakes, these double horizons may be indicative of several eruptions of Mount Mazama (S. Zoltai, pers. comm.).

The reappearance at microsite FL3 of *Scorpidium scorpioides* and *Drepanocladus revolvens* suggests wetter conditions, indicative of the end of this thermal event

about 4500 years B.P. Net organic accumulation increased from 0.005 to 0.009 g/cm²/yr with this transition, further indicative of wet conditions.

At the string and flark sites, vegetation changes occurred which cannot be correlated with the major trends occurring at microsite FL3. Local conditions, particularly those influencing pattern formation, were probably more influential at these microsites. Later discussion on string and flark formation will address these factors.

The rich fen at microsite FL3 persisted for about 1500 years before being succeeded by *Tomenthypnum nitens* and species of *Sphagnum*. Initial observations suggest that, with peat accumulation, the surface of the peatland had risen sufficiently to isolate it from the groundwater, and, thus, the drier elements invaded. However, the abruptness of this change prompts rejection of this interpretation. Evidence from diatom studies at Fairfax Lake, located about 25 km northeast of Muskiki Lake, also indicates drier conditions. A drop in planktonic diatoms and the increase in benthic forms suggest lowered lake levels (M. Hickman, pers. comm.). Although this environmental shift extends beyond the Muskiki Lake basin, the lack of evidence beyond the foothills area suggests a local phenomenon, perhaps associated with the Brazeau River drainage system.

Although some major environmental trends, such as increasing dryness around 7800 years B.P., are evident at the string and flark sites, local factors have played a

strong role in the development of the peatlands at Muskiki and Marguerite Lakes.

The basal peats at the string and flark sites indicate similar origins *i.e.*, terrestrial, wooded environments; however, the developmental sequences represented in the peat cores from these microsites are distinctly different, just as the present-day vegetation on the string and flarks are distinct.

The peat stratigraphies at these sites indicate that, although peat formation began about 7850 years B.P., string and flark formation did not begin until 4600 years B.P., following a sedge-meadow vegetation. However, these patterns were not stable, as several reversals have occurred.

Present hypotheses regarding the origin of string patterns have included the influence of permafrost processes (Schenk, 1963), the underlying lithology, and the rifting of peat during downslope slumping (ref. Zoltai, in press). More recently, theories of pattern formation based on the differential rates of peat accumulation integrated with other factors such as water flow and slope have become prominent (Sjors, 1961; Sakaguchi, 1980; Foster *et al.*, 1983; Seppala and Koutaniemi, 1985). Integrating our understanding of modern peatland dynamics with the vegetation and palaeoecological information available in the peat cores, the following interpretation of string and flark formation at Muskiki Lake is suggested.

First, initial accumulation of peat occurred due to poor drainage conditions and minimal evapotranspiration on the wooded upland with its gently sloped surface. Initial peat formers were dominated by species of *Sphagnum*. About 7000 years B.P., this *Sphagnum*-dominated community gave way to sedges and some brown mosses, interpreted as a sedge meadow, perhaps with open water. A rise in the water table, possibly due to a severe fire or a local beaver damming, may have been responsible. This excess of water on the gentle slopes undoubtedly allowed for sheet flow of water, rather than channel flow. Sheet flow may be critical to the development of strings and flarks (Thom, 1972; Sakaguchi, 1980; Seppala and Koutaniemi, 1985). If loose organic material was present, such as brown mosses which form loose mats in pools, sheet flooding could have easily carried this matter until obstacles appeared in its path. Sakaguchi (1980) believes that these obstacles which should be scattered uniformly across the ground surface could simply be tussocks of grass or sedges. The loose plant material would accumulate at right angles to the flow of water at these obstacles. Adjacent to these dammed areas, which provided a drier substratum for plant growth, would be depressions in which surface water formed pools. With the increased wetness in these hollows, the margins of the hollows expanded due to inhibited plant growth (Foster *et al.*, 1983; Seppala and Koutaniemi, 1985). Furthermore, increased microbial activity in the aerobic pools would

promote peat degradation, thereby enlargening and deepening the pools. The dammed areas, on the other hand, continued to develop due to the vigorous growth of *Sphagnum* and *Tomenthypnum*, which in turn allowed for the colonization of other species, such as shrubs, trees, and dry-loving bryophytes.

This hypothesis may well explain the origin of string and flark formation at Muskiki Lake, although a variety of other factors, both internal and external, will affect the development and preservation of these patterns.

The peat stratigraphies indicate that about 3500 years ago, the vegetation of the flark site became dominated by *Sphagnum* species and other dry habitat bryophytes including *Aulacomnium* and *Dicranum*, similar to the strings. The presence of *Sphagnum* in the flark may simply be due to the erosion and subsequent encroachment of the primary string such that secondary strings appear on either side. Subsequently, both string and flark sites became dominated by the brown mosses, perhaps due to decreased wetness and expansion of the flarks.

At Marguerite Lake, peatland development did not begin until the mid-Holocene, about 3400 years B.P., after the end of the thermal event. Although initial peatland development in Canada was closely related to deglaciation (Terasmae, 1977), the time delay between deglaciation and peat inception at Marguerite lake suggests another factor was responsible. The onset of peat accumulation at Marguerite

Lake may be related to the conclusion of the mid-Holocene period of warmth and aridity. Although the increase in moisture and cooling temperatures marking the end of this period arises about 4500 years B.P. at Muskiki Lake, a delay at Marguerite Lake may be due to the general dryness of this area relative to the foothills which experience the Pacific moisture influence. Additional evidence for a regional change to a cooler, moister climate at this time comes from lake sediment studies at Moore Lake, Alberta, about 20 km east of Marguerite Lake, which indicate increasing abundance of *Picea* and *Betula* with decreasing *Pinus* (Schweger, unpubl.).

Although adjacent to a fairly large lake, this Marguerite Lake peatland originated via paludification rather than lake-filling. This is especially evident from the presence of wood horizons at the base of each core, indicative of forested areas and a lack of lacustrine sediments and aquatic vegetation elements. This low-lying area became stabilized by an arboreal vegetation of *Larix laricina* which became paludified after the mid-Holocene. Conditions may have been favorable for the onset of peat accumulation, particularly for paludification upslope. However, waterflow during this wet period may have been too strong to allow for increased growth. This could help explain the very humified horizons at the base of the cores.

These forests were burnt within about 200 to 600 years of establishment, as evidenced by the presence of charcoal

and by the abrupt disappearance of wood from the stratigraphy. Subsequently, between 2600 and 3100 years B.P., *Drepanocladus revolvens* and *D. aduncus* rise to dominance. Proposing that the fire resulted in the shift to a wet, brown moss fen due to a rising water table is somewhat conjectural, as the impact of a fire may be very site-specific, depending on such factors as height of the water table, local vegetation, and the severity of the fire.

On the other hand, the increased wetness at Marguerite Lake may be related to one of several periods of increased humidity. Similarly, Payette (1984) cites several periods of increased humidity after 6000 years B.P., including about 3000 years B.P., which were favorable to peat growth in Quebec. Moreover, increased wetness may be corroborated by the change from humic to fibric peat. Such a change occurs, for example, at microsite ML3's core at about 2670 years B.P., as well as at Muskiki Lake at about 2760 years B.P., suggesting a regional climatic change.

The subsequent gradual development of Marguerite Lake peatland suggests autogenic successional processes. Whereas microsite ML1 becomes a drier, hummocky area dominated by *Larix*, *Drepanocladus*, *Tomenthypnum*, and *Meesia*, the calciphilic brown mosses including *Scorpidium*, *Campylium*, *Calliergon*, and *Drepanocladus* come to dominate microsites ML2 and ML3.

3.6 Conclusions

The peat stratigraphic studies at Muskiki and Marguerite Lakes' peatlands have shed some light upon the processes of succession in peatlands in central Alberta, such that several conclusions can be made.

First, there is no single pathway of development for peatlands in central Alberta. Several processes exist for the initiation of peat accumulation, including lake-filling and paludification. Even within a single peatland, peat onset can occur via different processes at different locations.

Furthermore, one cannot determine from the type of origin what sequence of development a peatland, or any particular site within it, will take. This fact expresses the significant role of both internal and external factors which can affect the course of peatland development. Of prime importance are deglaciation, topographic relief, drainage and moisture conditions, vegetation, and climate.

The impact of these factors is often site-specific, particularly local events such as fires and changes in drainage patterns, which affect moisture conditions. The influence of the environment, however, can also be widespread. A period of increased warmth and/or aridity between about 7200 and 4500 years B.P., for example, is suggested by vegetation changes visible at Muskiki Lake peatland, and in sediment cores from various Alberta lakes (Lichti-Federovich, 1970; Harris and Pip, 1973; Forbes,

1980; Hickman and Klarer, 1981; Schweger *et al.*, 1981; Vance *et al.*, 1983), and the apparent retardation of lake and peat inception in shallow basins, such as at Marguerite Lake.

Studies of peatland development provide an opportunity for examination of peat inception and accumulation, and the complex influence of both internal and external factors on this development. With a greater comprehension of a peatland's past, its present-day status and responses to environmental change may be more thoroughly understood and appreciated.

Table II-1. Radiocarbon dates from microsites FL1, FL2, and FL2 at Muskiki Lake peatland, and ML1, ML2 and ML3 at Marguerite Lake peatland (^{14}C years are converted, but not corrected).

	Depth (cm)	Time (^{14}C years)	Lab. Sample No.
FL1	110-119	2760±100	AECV #204C
	172-180	3670±150	AECV #205C
	313-322	7080±150	AECV #198C
	361-368	8480±190	AECV #206C
FL2	100-108	3300±100	AECV #207C
	185-195	4600±110	AECV #208C*
	300-310	6320±290	AECV #209C
	351-364	7850±400	AECV #129C
FL3	90-100	2800±120	AECV #210C
	210-219	4910±200	AECV #100C
	260-270	6260±120	AECV #128C
	325-335	7530±110	AECV #211C
	441-450	9000±230	AECV #103C
ML1	60-72	1660±120	AECV #199C
ML2	60-74	1810±100	AECV #201C
	117.5-124	2750±150	AECV #202C
ML3	112.5-130.5	2670±150	AECV #203C
	181-188	3400±160	AECV #97C

Table II-2. Radiocarbon dates, peat accumulation rates and net organic production at three microsites at Muskiki Lake peatland (FL1, FL2, FL3) and two microsites at Marguerite Lake peatland (ML2, ML3).

Site	Depth (cm)	Mean Dry Bulk Density (g/cm^3)	Radio-Carbon Age (^{14}C yrs)	Peat accumulation Rate (cm/yr)	Net Organic Production ($g/cm^2/yr$)
FL1	114.5-176	0.139	2760-3670	0.068	0.006
	176 -317.5	0.178	3670-7080	0.041	0.007
	317.5-364.5	0.162	7080-8084	0.034	0.009
FL2	104 -190	0.117	3300-4600	0.066	0.005
	190 -305	0.174	4600-6320	0.067	0.012
	305 -357.5	0.142	6320-7850	0.034	0.008
FL3	95 -214.5	0.158	2800-4910	0.057	0.009
	214.5-265	0.137	4910-6260	0.037	0.005
	265 -330	0.162	6260-7530	0.051	0.008
	330 -445.5	0.194	7530-9000	0.079	0.015
ML2	67 -120.8	0.106	1810-2750	0.057	0.006
ML3	126.5-184.5	0.106	2670-3400	0.079	0.008

Table II-3. Moisture preference values for identifiable species in peat from microsite FL3 at Muskiki Lake peatland. Values are based on modern habitat preferences (Janssens, 1981; Vitt and Slack, 1984).

Species	Moisture Preference Value
Aulacomnium palustre	1
Calliergon sp.	5
Campylium sp.	4
Chara sp.	5
Drepanocladus exannulatus	5
D. revolvens	5
Meesia triquertra	4
Paludella squarrosa	3
Scorpidium scorpioides	5
Sphagnum warnstorfii	3
Tomenthypnum nitens	1

Table II-4. Vegetation at microsites FL1, FL2 and FL3 at Muskiki Lake peatland at 3 time-synchronous planes: 1) present; 2) time of St. Helens Y ash deposition (approximately 3500 years B.P.); and 3) time of Mazama volcanic ash deposition (about 6800 years B.P.).

		FL1	FL2	FL3
Present	Depth	0 cm	0 cm	0 cm
	Vegetation	Sphagnum	brown mosses	Sphagnum
St. Helens Y	Depth	163-169 cm	137-140 cm	109-134 cm*
	Vegetation	Tomenthypnum	brown mosses	brown mosses
Mazama	Depth	268-294 cm & 304-311 cm	262-277 cm	222-232 cm & 271-289 cm
	Vegetation	sedges and brown mosses	sedges	Sphagnum

*Depth of sample which included ash deposit.

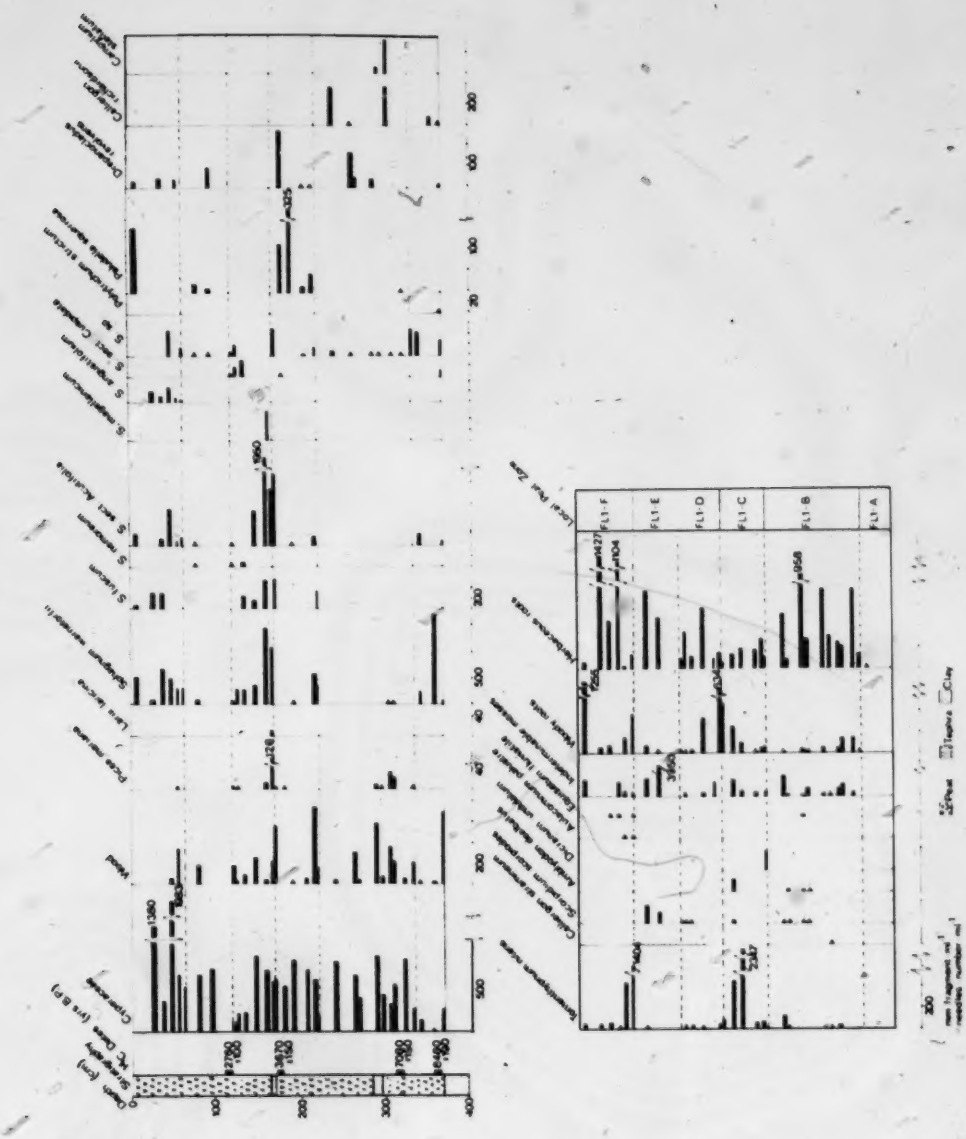

Figure 8.1 Plant macrofossil and stratigraphic diagram for macrozone FL1 at Muskiki Lake, central Alberta.

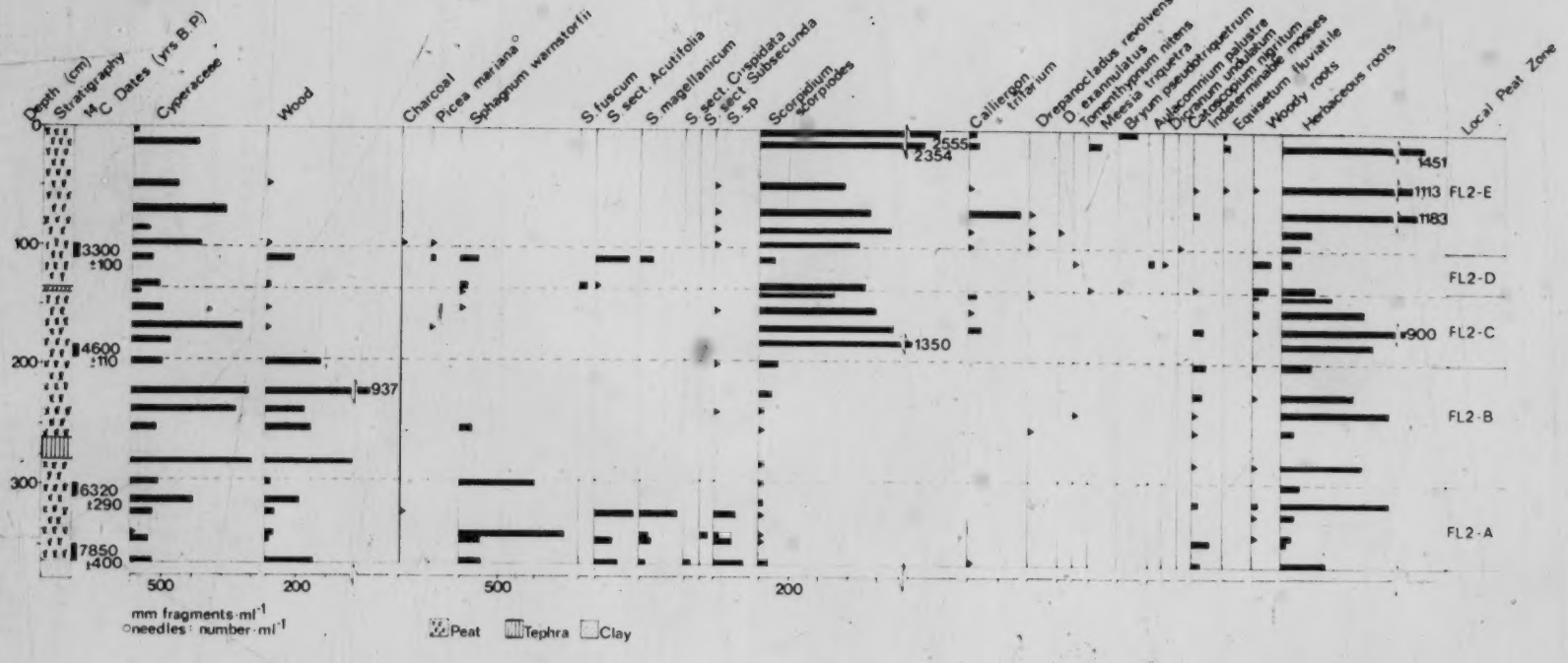

Figure II-2 Plant macrofossil and stratigraphic diagram for microsite FL2 at Muskiki Lake peatland, Alberta.

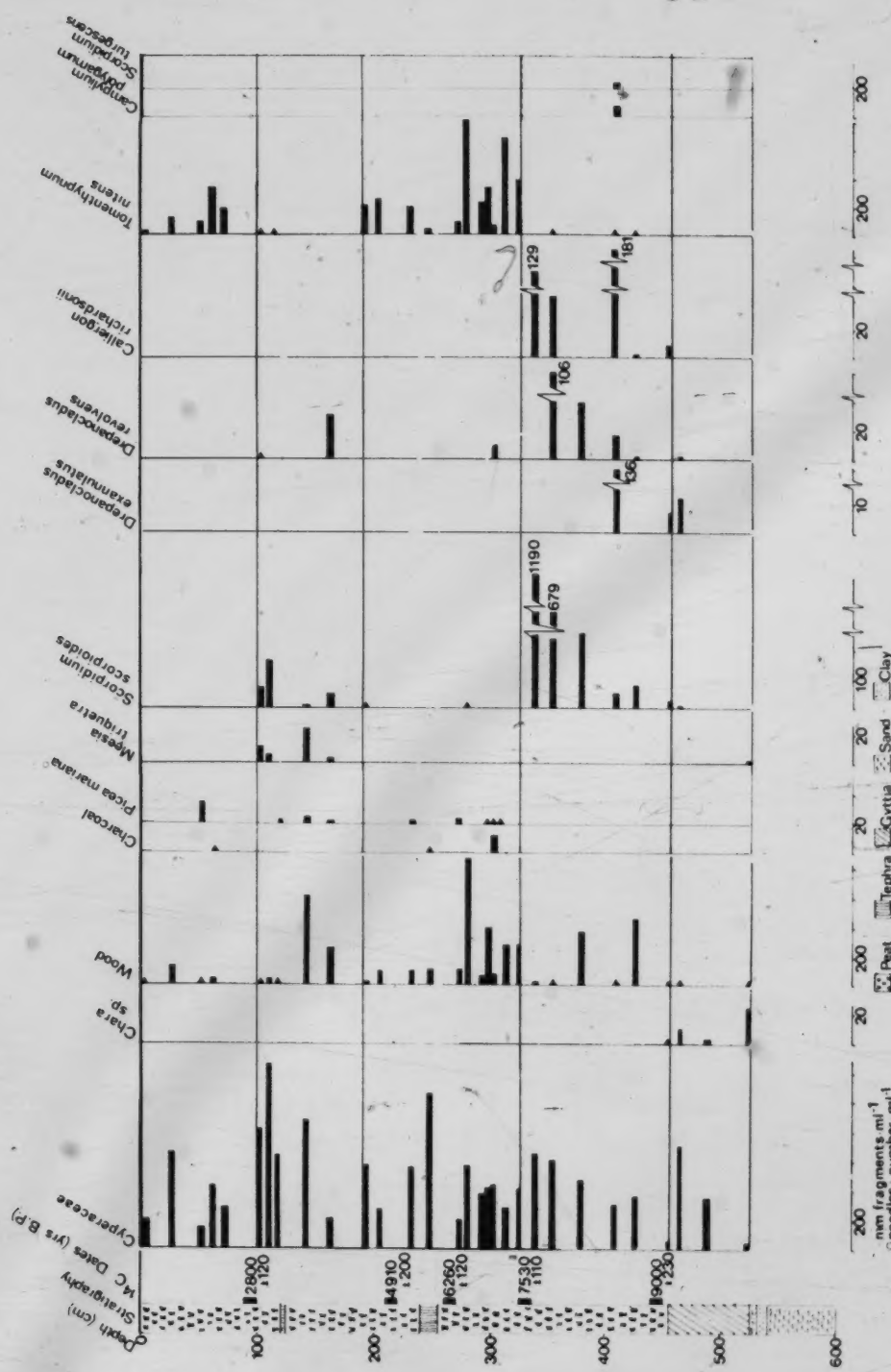

Figure 13. Plant macrofossil and stratigraphic diagram for microsite FL3 at Muskiki Lake peatland, Alberta (Continued on next page)

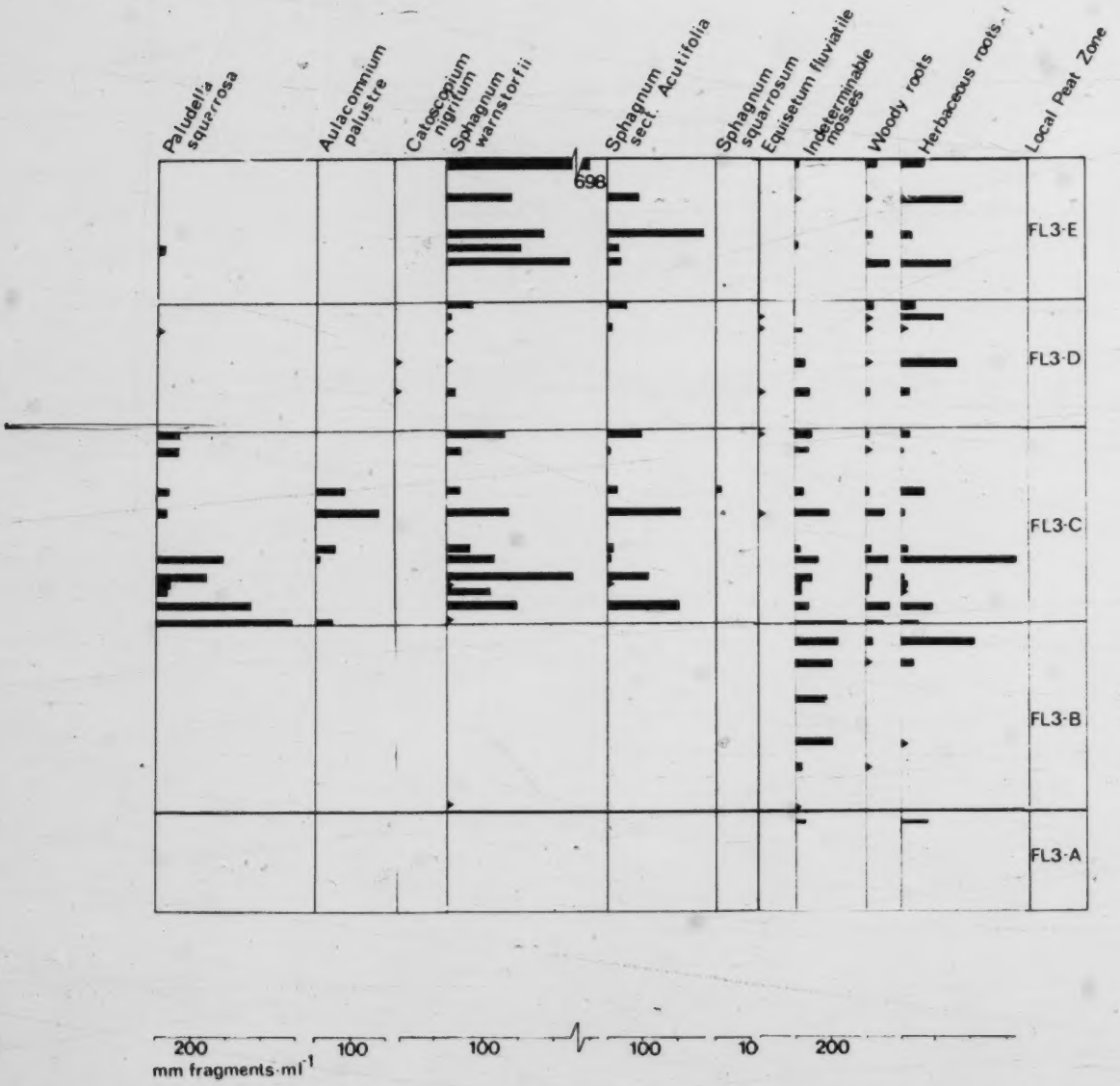

Figure II-3. (Continued)

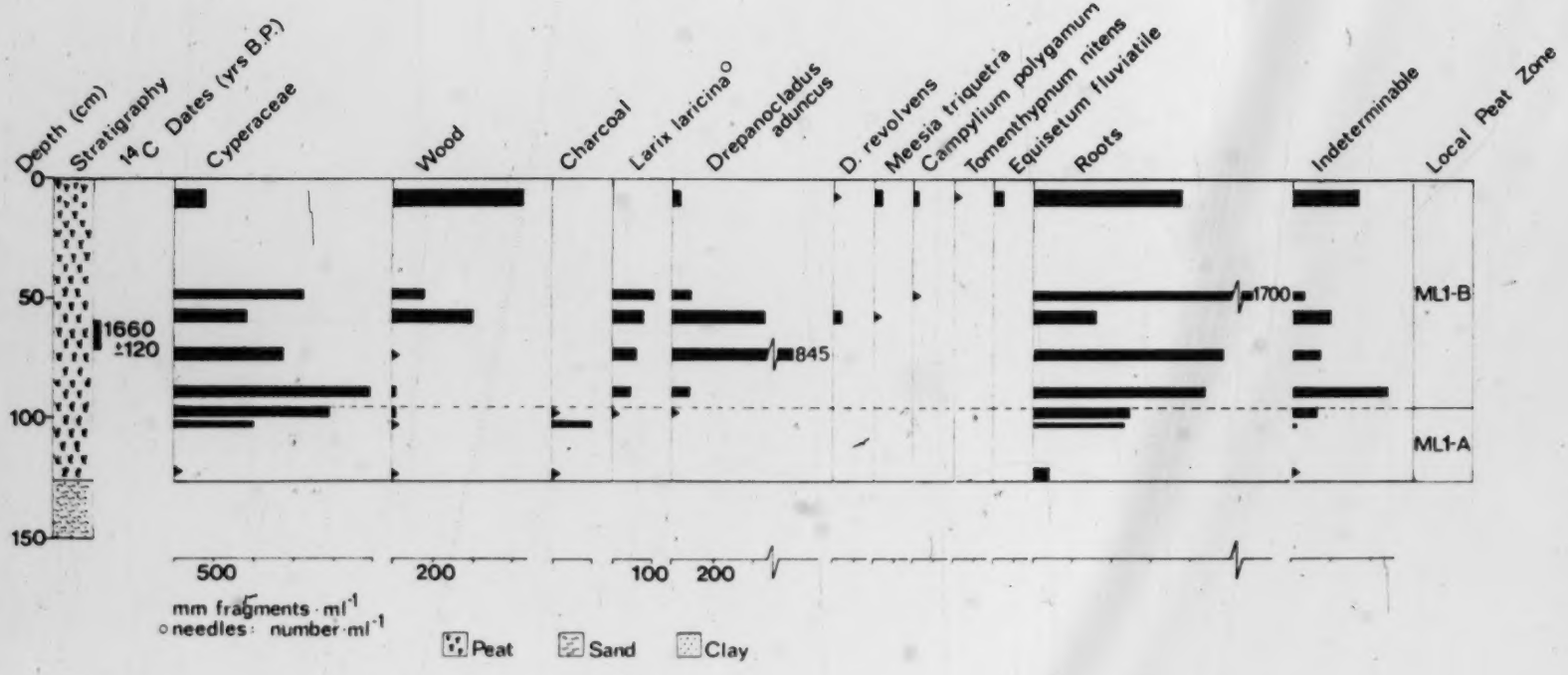

Figure II-4. Plant macrofossil and stratigraphic diagram for microsite ML1 at Marguerite Lake peatland, Alberta.

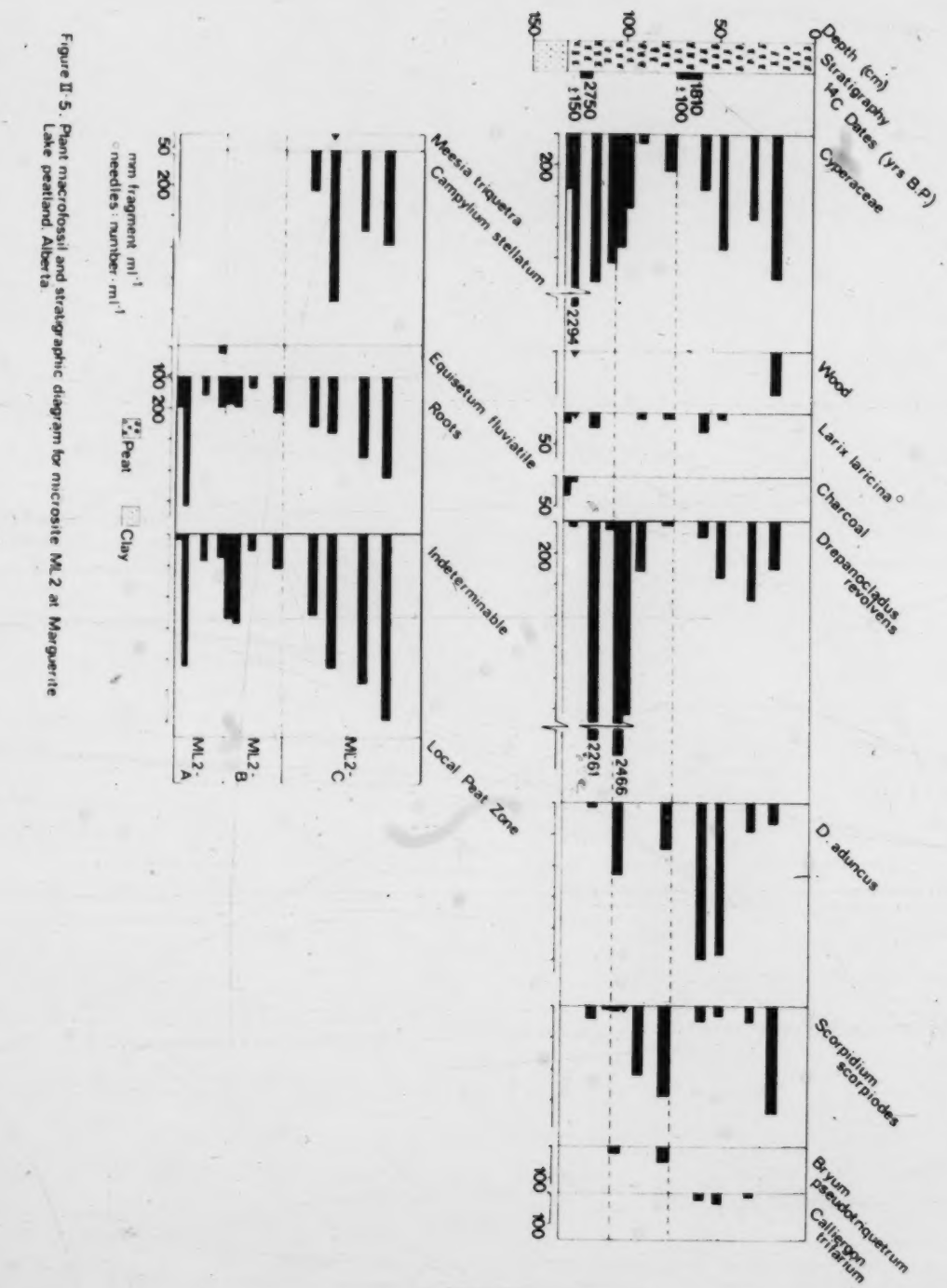

Figure II-5. Plant macrofossil and stratigraphic diagram for microsite ML2 at Marguerite Lake peatland, Alberta.

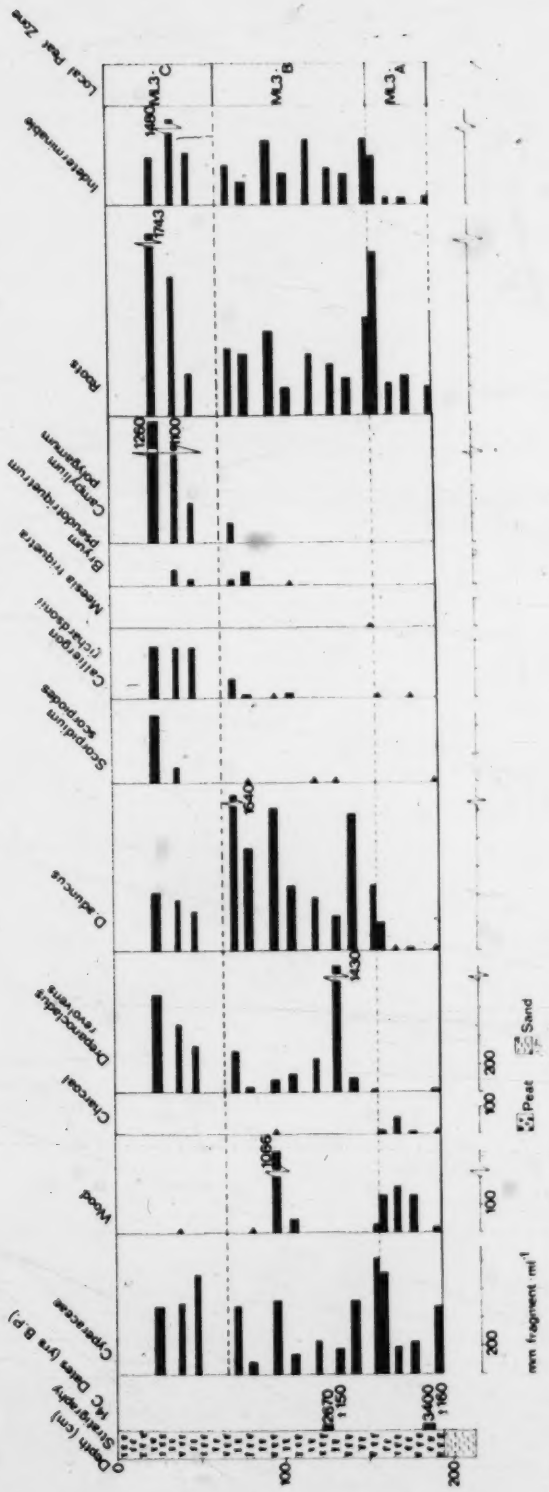

Figure II-6. Plant macrofossil and stratigraphic diagram for microsite ML3 at Marguerite Lake peatland, Alberta.

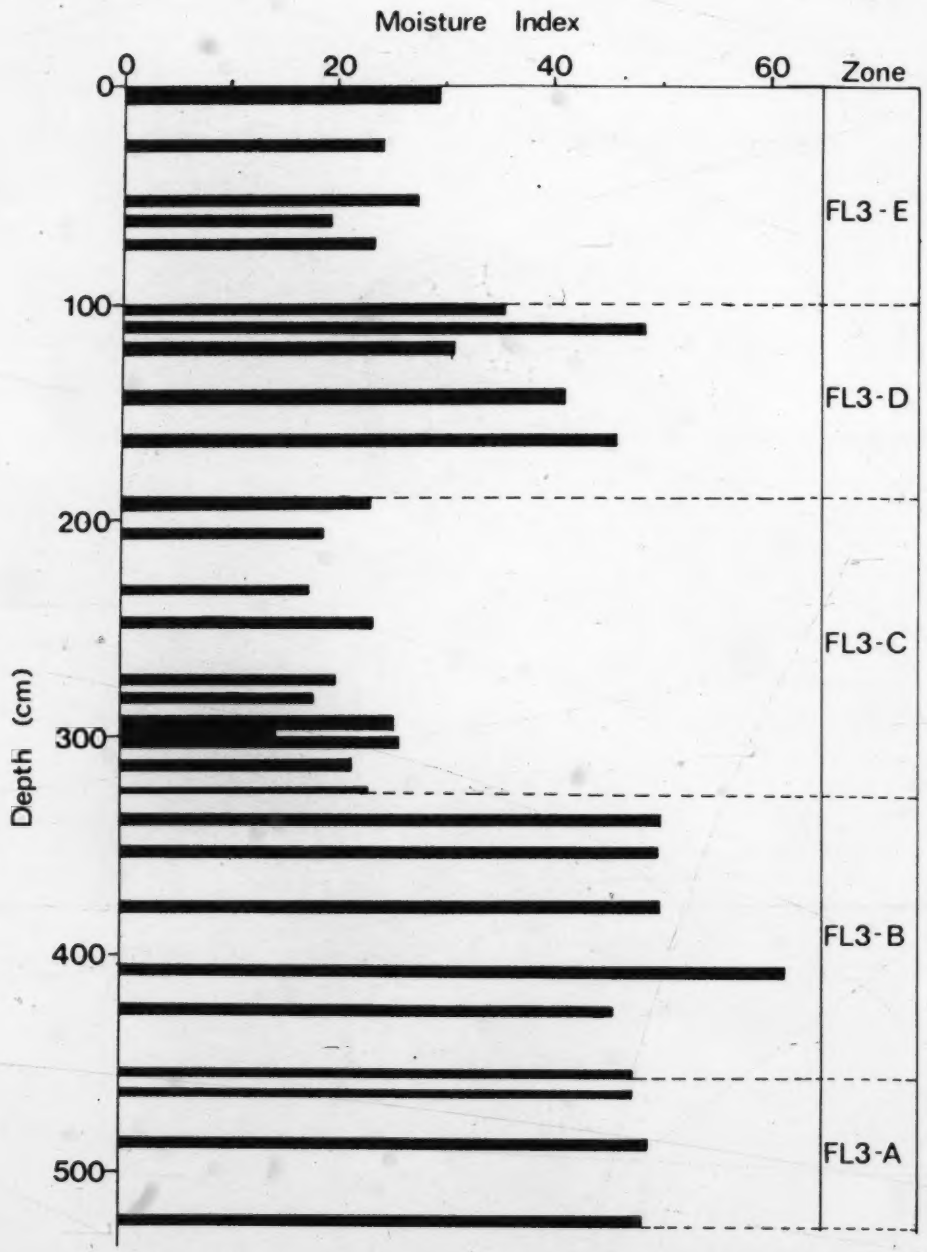

Figure II-7. Moisture index changes with depth at microsite FL3 at Muskiki Lake peatland. Moisture index for each sample depth is based on the sum of the product of each species' concentration and moisture preference value.

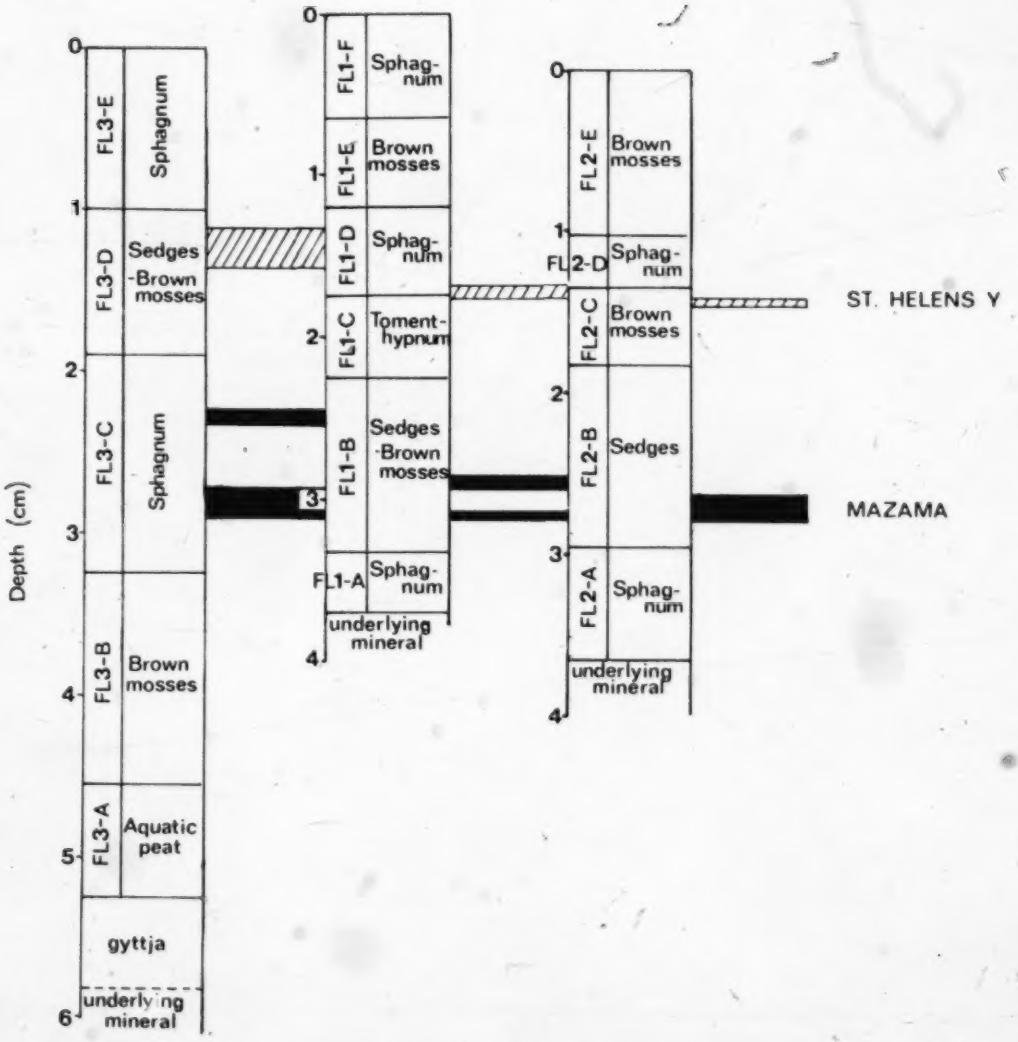

Figure II-8. Correlation of peat stratigraphies from microsites FL1, FL2, and FL3 at Muskiki peatland, based on Mazama ■ and St. Helens Y ▨ tephra deposits.

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4. General Discussion and Conclusions

Examination of the peat and water chemistry, and developmental records of the peatlands at Muskiki and Marquerite Lakes have provided additional information for the study of the general nature of peatlands in Alberta. Foremost, this information, however limited, indicates the variability between peatlands in this region.

According to the peatland chemistry, Muskiki Lake peatland is an extreme rich fen with high cation status, and pH generally greater than 7.0. Marguerite Lake peatland, on the other hand, may be considered a transitional rich fen, with lower calcium concentrations, and lower pH (5.9-6.7), although conductivity, and magnesium and nitrogen concentrations may be elevated.

These minerotrophic fens are very similar, with basic vegetation of brown mosses (family Amblystegiaceae), carices, and shrubs of *Betula* and *Salix*, with few species of *Sphagnum* present. The peat stratigraphies, however, indicate that these peatlands have very different developmental histories, including a 5600 year difference in peat inception times.

The onset of peat accumulation at Muskiki Lake began via lake-filling about 9000 years B.P. in response to deglaciation and a changing climate. An expansion of this peatland occurred about 7850 years B.P. by paludification of a wooded area farther upslope from the lake. Subsequent environmental events, including a mid-Holocene period of

warmth and aridity between about 7200 and 4500 years B. P., and another dry period beginning about 2800 years B.P., resulted in changes in vegetation. Generally, the brown mosses dominated the wet periods, and *Sphagnum* and other mosses, such as *Tomenthypnum*, dominated the drier periods. Farther upslope, string and flark formation began about 4600 years B. P., although expansion and contraction of these patterns occurred. The present-day vegetation arose between 2300 and 3200 years B. P.

Compared to Muskiki Lake peatland, peat inception at Marguerite Lake was significantly delayed, probably due to a later deglaciation and the subsequent mid-Holocene warm period. Processes of lake-filling were not evident here, although paludification of forested areas occurred about 3400 years B. P. Charcoal, indicative of fire activity, marks the decline of the forest communities between 2600 and 3100 years B. P., and the beginning of a wet fen, dominated by brown mosses. Brown mosses continue to dominate the present-day vegetation, although autogenic successional processes have altered species composition and abundance over the past 3000 years.

Although both peatlands have been influenced by several regional climatic events, such as the mid-Holocene thermal event, and periods of increased humidity favourable to peat accumulation, local factors, such as flooding and fire, have played a significant role in their developmental patterns.

At each peatland, an environmental change elicits a specific vegetation response, determined by a complex of factors. These factors, which include peat and water chemistry, are fundamental to peatland development, since they define the peatland's response to change, particularly with respect to the species which will inhabit the peatland at each successive stage.

There may be some value in examining peat and water chemistry in order to provide some insights into the developmental patterns of these peatlands. Parameters such as bulk density and the degree of humification may provide some clues about the environments in which the peat was formed, particularly with respect to the degree of moisture (Aaby and Tauber, 1975). These parameters are particularly useful if coupled with radiocarbon dates, as rates of peat accumulation and net organic production can be determined. On the other hand, the instability of the chemical status of peat and water makes the use of these factors in interpreting processes of peatland development uncertain.

Several conclusions can be made. First, this study has shown the variation in developmental patterns between fens at Muskiki and Marguerite Lakes in central Alberta. Significant differences between these two peatlands include the time and the determinants of initial peat accumulation, and the subsequent influences of various internal and external factors such as fire and thermal events which affect peatland development. Second, the chemical status of

each peatland stresses the differences in classification. Higher nitrogen concentrations, and lower pH and ionic concentrations support the designation of Marguerite Lake peatland as a transitional rich fen, whereas higher pH and ionic conten, coupled with much lower nitrogen content at suggests a rich fen designation. Further investigations regarding peatland development in Alberta and elsewhere, and the significance of various internal and external factors of ecological importance may enrichen our knowledge and understanding of peatland dynamics.

5. Appendices

5.1 Total ionic content in water samples

Total ionic content (mg/l) of 14 elements in water samples from microsites at Muskiki Lake (FLA, FL1, FL2, FL3) and at Marguerite Lake (MLA, ML1, ML2, ML3) peatlands. Mean values are based on sample size of 3 (+ = below detection limit of I.C.P.S.).

Microsite	Ca	Mg	Na	K	Al	Ti	Pb	Cu	Fe	Mn	Zn	Ni	S	P
FLA	32.06	8.67	3.83	0.57	+	+	+	0.01	0.12	0.01	0.05	0.02	0.76	+
FL1	49.30	11.28	2.31	0.96	0.09	+	+	0.01	0.67	0.02	0.06	0.07	0.89	0.09
FL2	64.37	13.95	2.16	0.30	0.07	+	+	0.01	0.41	0.02	0.07	0.05	0.62	+
FL3	54.53	12.32	2.03	1.12	0.08	+	+	0.02	0.42	0.22	0.07	0.05	0.41	0.09
MLA	33.31	54.68	13.38	6.84	0.37	+	+	+	1.11	0.11	0.18	0.02	0.31	+
ML1	20.75	5.60	2.42	0.97	+	+	+	0.01	1.78	0.25	0.02	0.08	0.36	0.14
ML2	26.10	20.58	6.19	2.41	0.16	+	+	0.01	0.38	0.03	0.08	0.04	0.31	0.09
ML3	26.82	30.84	8.65	7.64	+	+	+	+	0.54	0.01	0.02	0.02	0.08	+

5.2 Field designations at Muskiki Lake Peatland

Field designations of horizons, von Post degree of humification and pH, and moisture content (%) of peat at microsites FL1, FL2, and FL3 at Muskiki Lake peatland.

Microsite	Depth (cm)	Horizon	von Post	pH	Moisture (%)
FL1	0-21	Of	3	6.0	88.5
	21-35	Of	2	6.0	90.6
	35-43	Of	4	6.0	86.2
	43-72	Of	3	6.0	85.3
	72-86	Of	3	6.2	83.4
	86-124	Of	4	6.2	85.7
	124-130	Om	5	6.0	67.4
	130-169	Of	3	6.0	85.6
	169-205	Of	4	6.0	85.4
	205-286	Of	4	6.2	86.8
	286-294	Of	5	6.2	68.6
	294-384	Of	5	6.3	82.3
	304-311	ash			55.5
	311-332	Of	4	6.3	82.2
	332-340	Om	5	6.3	82.0
	340-362	Of	4	6.2	85.7
	362-372	Om	6	6.2	85.7
	372 +	C (clay)			33.4
FL2	0-63	Of	2	6.0	92.1
	63-108	Om	5	6.0	88.2
	108-127	Of	3	6.0	91.2
	127-140	Of	4	6.0	79.1
	140-172	Of	3	6.0	76.7
	172-262	Om	5	6.5	86.3
	262-290	Om	6	6.5	79.1
	290-314	Oh	7	6.5	80.7
	314-323	Om	5	6.5	83.5
	323-371	Of	4	6.5	90.4
	371-384	Om	5	6.5	80.3
	384 +	Cg (Clay)			24.9
FL3	0-64	Of	4	6.1	89.4
	64-85	Of	2	6.1	91.3
	85-109	Of	3	6.1	84.4
	109-134	Of	4	6.1	77.2
	134-222	Om	5	6.2	85.2
	222-232	ash	4	6.1	50.7
	232-238	Of	4	6.2	63.2
	238-241	Om	6	6.1	84.8
	241-258	Of	4	6.2	86.0

258-289	Of	3	6.3	72.5
289-357	Of	3	6.1	85.6
357-414	Of	3	5.9	86.8
414-479	Oh	7	6.3	66.6
479-581	Oh	8	6.4	52.8
581 +	C (sand,clay)			28.1

5.3 Correlations of factors at Muskiki Lake peatland

Correlations between peat depth, dry bulk density (g/cm³), ash content (%) and moisture content (%) at microsites FL1, FL2 and FL3 at Muskiki Lake peatland.
Sample size is indicated in brackets.
Confidence interval is 95%.
* indicates significant values.

Microsite FL1 (13)

	Depth	Bulk Density	Ash
Bulk Density	0.516*		
Ash	0.382	0.870*	
Moisture	-0.361	-0.976*	-0.777*

Microsite FL2 (12)

	Depth	Bulk Density	Ash
Bulk Density	0.620*		
Ash	0.387	0.730*	
Moisture	-0.490	-0.895*	-0.876*

Microsite FL3 (18)

	Depth	Bulk Density	Ash
Bulk Density	0.698*		
Ash	0.664*	0.906*	
Moisture	-0.754*	-0.992*	-0.914*

5.4 Total elemental content of peat at Muskiki Lake peatland

Total elemental content (x 10^{-3} mg/g) of nine elements with peat depth at three microsites at Muskiki Lake peatland. Mean values are based on sample size of 3 (+=below detection limit of ICPS)

Microsite	Depth (cm)	Al	Ti	Pb	Cu	Fe	Mn	Ni	S	P
FL1	0-21	1334.9	13.9	2.5	8.2	2870.2	126.7	3.4	2211.5	810.4
	21-35	907.0	10.3	1.5	6.0	1402.2	16.3	2.6	1655.0	338.4
	35-43	1877.2	16.7	2.4	3.2	1558.2	12.7	4.2	1910.1	538.8
	43-72	1448.6	15.6	10.4	10.8	1630.5	14.0	3.2	2230.3	332.1
	72-86	1841.4	16.0	2.2	7.4	1533.4	9.8	3.3	3134.9	515.3
	86-124	1171.4	13.8	1.6	3.6	1198.0	6.9	3.1	2511.6	383.8
	124-130	12563.8	256.6	14.4	6.7	1065.9	8.9	2.8	1733.9	313.0
	130-169	3534.1	47.4	2.9	6.2	1772.5	6.8	2.6	3010.9	216.8
	169-205	1070.5	13.4	1.8	10.7	2292.0	7.5	3.0	2080.7	336.0
	205-286	1092.9	17.8	1.7	4.9	2783.9	12.5	2.3	2794.3	294.3
	286-294	10716.7	279.5	12.8	28.9	2451.0	37.0	7.6	1239.6	488.7
	294-384	10303.2	387.9	11.3	11.0	3513.5	19.0	2.9	4670.4	467.4
	304-311	6224.9	142.2	13.6	19.8	1864.6	34.1	3.4	1325.2	328.2
	311-332	1665.1	28.5	3.1	11.0	8240.1	26.5	5.2	7835.6	288.6
	332-340	2318.7	28.7	3.3	8.3	9785.2	30.0	6.3	8445.3	183.2
	340-362	1710.7	23.8	4.2	21.8	11086.2	27.3	10.3	9225.1	143.3
	362-372	6530.5	16.8	18.3	17.8	14240.0	41.8	31.8	10868.5	341.3
	372 +	9337.6	0.4	14.9	6.4	1880.3	173.4	22.9	915.0	+
FL2	0-63	652.8	9.3	9.5	9.4	10692.6	284.4	6.0	2730.7	481.7
	63-108	1583.6	20.5	3.2	8.1	3685.0	22.5	4.7	3945.8	311.5

	108-127	979.6	13.1	1.2	7.3	3359.4	18.1	4.1	3228.6	254.1
	127-140	4803.2	89.9	5.0	257.0	1946.2	14.0	3.2	2411.3	404.3
	140-172	4753.5	118.9	4.4	12.6	1887.0	20.6	3.0	2641.6	423.1
	172-262	1139.1	19.0	1.5	7.0	3163.2	20.8	3.0	3791.4	298.6
	262-290	9382.0	233.8	10.6	92.5	5364.5	22.8	2.8	5129.1	578.7
	290-314	8923.4	203.9	9.2	15.0	8227.7	24.9	4.1	7165.3	626.9
	314-323	1890.3	26.2	1.7	5.5	10340.4	25.7	5.7	9130.9	160.2
	323-371	1077.2	22.7	1.7	3.7	11827.2	26.2	6.4	11554.3	104.1
	378-384	5014.5	12.1	10.8	85.6	23015.5	47.0	60.7	154162.2	365.9
	384 +	10607.4	3.2	20.7	7.1	10512.5	86.0	24.1	1323.5	409.9
FL3	0-64	1465.7	17.6	8.9	11.3	2024.2	30.7	5.2	514.8	461.4
	64-85	836.6	11.4	4.4	11.9	1004.1	13.7	7.6	3968.2	364.2
	85-109	2598.1	31.1	3.5	8.2	993.3	16.0	9.7	6783.5	527.5
	109-134	7513.2	194.2	9.1	8.6	1502.7	15.6	6.7	3714.0	535.9
	134-222	1992.9	32.4	4.4	11.2	1648.1	12.0	5.9	8164.2	585.9
	222-232	9460.4	2.7	14.5	12.1	147.0	45.9	7.4	714.4	3.2
	232-238	9532.4	0.3	19.1	7.4	86.9	36.0	15.4	5684.7	+
	238-241	13924.4	887.2	17.7	13.3	8594.9	21.0	9.8	14568.0	358.2
	241-258	1047.7	12.0	2.1	14.6	2670.1	14.9	7.7	9711.9	514.6
	258-289	6631.4	4.5	13.0	70.7	2561.6	28.9	14.4	10046.6	169.1
	289-357	3067.0	11.4	6.9	11.9	3218.9	16.1	8.6	10077.8	482.1
	357-414	1939.1	12.5	6.4	18.1	2660.4	11.1	13.8	9860.8	416.2
	414-479	7234.5	3.8	12.9	9.0	3909.2	96.0	17.7	11169.7	96.7
	479-581	4281.8	8.2	11.2	25.8	5505.2	169.7	10.8	7696.6	169.3
	581 +	7071.0	6.1	16.6	12.2	8222.9	222.1	14.1	6030.0	247.0

5.5 Field designations at Marguerite Lake peatland

Field designations of horizons, von Post degree of humification and pH, and moisture content (%) of peat at microsites ML1, ML2, and ML3 at Marguerite Lake peatland.

Microsite	Depth (cm)	Horizon	von Post	pH	Moisture (%)
ML1	0-34	Of	1	5.0	--
	34-66	Of	3	5.0	89.6
	66-94	Of	4	6.0	83.5
	94-136	Of	6	6.5	28.5
	136 +	C (sand)			23.4
ML2	0-13	Of	1	6.5	84.9
	13-110	Of	3	6.5	91.0
	110-110	Of	4	6.5	83.5
	119-129	Oh	7	7.0	74.1
	129 +	C (clay)			25.6
ML3	0-50	Of	3	6.0	89.0
	50-114	Of	3	6.5	91.1
	114-122	Of	4	6.5	90.2
	122-143	Of	2	6.5	90.6
	143-176	Of	5	6.5	90.1
	176-187	Om	5	6.5	85.3
	187-190	C (sand)		6.5	53.0
	190 +	C (sand)		7.0	22.0

5.6 Correlations of factors at Marguerite Lake peatland

Correlations between peat depth, dry bulk density (g/cm³), ash content (%) and moisture content (%) at microsites ML1, ML2 and ML3 at Marguerite Lake peatland. Sample size is indicated in brackets. Confidence interval is 95%.
* indicates significant values.

Microsite ML1 (8)

	Depth	Bulk Density	Ash
Bulk Density	0.932*		
Ash	0.861*	0.978*	
Moisture	-0.912*	-0.989*	-0.996*

Microsite ML2 (7)

	Depth	Bulk Density	Ash
Bulk Density	0.743*		
Ash	0.770*	0.922*	
Moisture	-0.691	-0.994*	-0.968*

Microsite ML3 (10)

	Depth	Bulk Density	Ash
Bulk Density	0.620*		
Ash	0.647*	0.999*	
Moisture	-0.649*	-1.000*	-0.971*

5.7 Total elemental content of peat at Marguerite Lake peatland

Total elemental content (x 10^{-1} mg/g) of nine elements with peat depth at three microsites at Marguerite Lake peatland. Mean values are based on sample sizes of # (+=below detection limit of ICPS)

Microsite	Depth (cm)	Al	Ti	Pb	Cu	Fe	Mn	Ni	S	P
ML1	0-34	805.0	9.4	3.9	12.4	5298.4	165.1	5.2	588.4	670.7
	34-66	728.9	9.8	0.8	7.5	5503.3	215.9	4.1	828.3	714.8
	66-94	735.9	12.7	2.2	17.0	9433.0	218.4	8.7	1040.8	623.3
	94-136	3800.9	28.0	9.5	8.2	3712.3	49.6	8.7	249.9	152.4
	136 +	4598.1	38.5	7.0	2.4	3790.2	33.5	7.2	164.5	89.5
ML2	0-13	829.2	14.2	4.3	12.8	1818.4	467.0	4.5	591.1	629.8
	13-110	643.9	16.4	1.0	10.2	1949.3	77.1	3.2	990.3	618.0
	110-119	2625.2	45.8	3.6	13.8	3944.3	117.0	11.6	1046.3	612.0
	119-129	6517.1	81.1	14.7	8.9	5076.8	137.8	10.5	522.4	538.6
	129 +	10240.3	103.4	14.9	7.3	8376.8	266.2	12.7	78.7	350.8
ML3	0-50	856.6	14.8	2.7	8.0	1122.9	27.5	2.4	508.7	581.2
	50-114	777.3	14.9	1.4	10.5	1545.0	35.8	2.9	803.9	584.4
	114-122	861.0	17.2	1.9	9.6	2161.3	47.3	2.6	911.5	687.5
	122-143	669.2	14.7	1.3	4.6	1824.1	39.6	2.8	756.2	556.5
	143-176	630.1	11.7	0.5	14.5	2014.4	44.9	2.4	1138.8	498.7
	176-187	1694.7	38.9	4.4	15.4	2407.9	64.0	4.9	2267.8	565.7
	187-190	1436.5	42.7	2.4	3.0	1686.9	21.3	2.5	290.6	134.3
	190 +	2156.8	49.8	3.8	6.4	1894.5	20.8	5.0	158.2	111.8